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AN INVESTIGATION INTO THE POSSIBILITY OF FORECASTING LOW LEVEL WIND SHEAR FOR AVIATION

by

W.G. Durbin

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AN INVESTIGATION INTO THE POSSIBILITY OF FORECASTING LOW LEVEL WIND SHEAR FOR AVIATION

by

W. G. DURBIN B.Sc.

ABSTRACT

With the realisation that low level wind shear has been the cause of a number of major aircraft accidents, it has become necessary to seek means of predicting its occurrence.

Two trials, one in the winter and the other in the summer, each lasting for three months during 1977 were carried out to test a set of forecasting rules that had been devised. From an examination of a number of meteorological parameters that were logged hourly, forecasters at 3 civil airports and up to 8 RAF stations were required to assess the need to issue a warning every hour that the station was operational. Aircrew were asked to report both verbally and on specially prepared forms on the occurrence of shear, whether forecast or not, and from the information that became available from these various sources, the success of the rules was assessed.

During the winter trial 606 warnings during 6984 operational hours were issued at the civil airports compared with 402 warnings during 8450 hours at the RAF stations. In the summer trial, the figures were 187 warnings in 6624 hours and 132 warnings in 10,383 hours for the civil and RAF stations respectively.

From the detailed analysis carried out it is concluded that from considerations of (a) the 10m and gradient wind speeds

(b) the proximity of cumulonimbus clouds and thunderstorms

and (c) the proximity and certain characteristics of fronts,

a warning system is feasible. Specific recommendations are made.

Advantage was taken of the opportunity to investigate such non-meteorological aspects of wind shear as its effect on different types of civil and RAF aircraft. It is suggested that Tristars are more susceptible and Tridents less so to consequential handling difficulties than other civil aircraft that took part in the trials. On the RAF side, Buccaneers appeared to be the least affected by slight shear.

1. INTRODUCTION

Aviation has been developed to the point where it is so safe that although there have been reports on take-off or landing of aircraft incidents and accidents for which the causes were not obvious, there has been a tendency in the absence of a more plausible explanation to attribute them to pilot error. It began to be suspected that in many cases the cause could have been low level wind shear and with the later realisation that this was often the case, it has come within the last decade or so to be identified as a hazard. Although perhaps arguable, the statement has appeared in an authoritative publication (1) that:

'the means to determine and predict the existence of wind shear has become the most pressing single requirement of meteorology in our time"

In support of this there have been several major accidents for which, following exhaustive investigations, the cause was attributed unequivocally to low level wind shear. The worst of these was to an Eastern Airlines B727 which crashed on landing at New York's Kennedy Airport in June 1975 and was destroyed by impact and fire with the death of 113 of the 124 people on board. In the report on the investigation into another major accident, this one at Denver, Colorado in August 1975 (2) the final recommendation was to:

'expedite the development of a programme leading to the production of accurate and timely forecasts in the terminal area".

This, briefly, is the background to meetings which were held under the auspices of the Civil Aviation Authority in 1975 and 1976 to decide what, if any, British contribution could or should be made to the problem. It was decided among other things that as enough was thought to be known of the meteorological conditions under which low level wind shear occurs, it would be possible to devise a set of forecasting rules and to test them in collaboration with British Airways crews who would report on the occurrence of low level wind shear on take-off or landing, whether forecast or not, at three selected civil airports. In the event the Royal Air Force also agreed to participate and eventually eight of its stations were involved. It was hoped that from this would emerge a worthwhile operational procedure for use on a permanent basis.

2. DETAILS OF THE INVESTIGATION

2.1. The investigation took the form of two trials, each lasting for three months in 1977. The first was during the winter from January 9 to April 20 and the second was in the summer from July 1 to September 30. The reasons for holding a second trial were partly to augment the data from the earlier trial and partly to see if any significant difference could be detected between low level wind shears likely to be experienced in winter and summer. More particularly it was wished to cover the period of summer thunderstorms some of which, moreso than those that occur in winter, were likely to have characteristics which would render them capable of giving rise to wind shear of a type and severity as have been deemed to have caused or contributed significantly to the causes of such well documented aircraft accidents as that at Kennedy airport referred to in the introductory section 1 above. The summer trial differed in the light of experience from the earlier winter trial and this created some problems of comparison. Both suffered to some extent from strikes which grounded civil aircraft for much of April and reduced the amount of civil traffic during September. Nevertheless, sufficient information became available for both trials to have achieved their objects.

2.2 The civil stations involved in both trials were London (Heathrow), Birmingham (Elmdon) and Glasgow (Abbotsinch). Of the RAF stations taking part in the winter trial, Honington and Brize Norton operate 24 hours per day every day and Scampton, Marham, Wyton and Waddington operate during weekdays only and usually not at night. Additionally, St. Mawgan and Kinloss, both 24-hour stations, participated during August and September of the second trial.

2.3. The rules used as guide-lines for the issue of the low level wind shear warnings are given in Appendices A (winter trial) and F (summer trial). Rules 1-4 were concerned with the 10 metre and gradient winds.

2.3.1. Without intending to imply that there could be no significant low level shear with light 10 metre winds, Rule 1 was based on the argument that there is, nevertheless, more likely to be shear if they are stronger and the lower limit of V_{10} for which, regardless of any other considerations, it was assumed there would be significant shear, was taken to be 30 kn.

2.3.2. Rule 2 which was used for the winter trial only is a reflection of the gradient wind speed normally being about twice that of the 10 metre wind and that if it should be significantly in excess of this it would likely be due to a layer containing shear. The limits used in Rule 2 were $V_{10} > 10$ kn and $V_G - 2V_{10} \geq 25$ kn and this meant, for example, that V_G would have to be at least 45 kn if V_{10} were 10 kn (representing 35 kn of shear between 10 and 600 m) but greater than this if V_{10} were > 10 kn.

2.3.3. Rules 3 and 4 were vector rules to take wind direction as well as speed into account and as used for the winter trial were specific to V_{10} being less than 10 kn. The reasoning behind them was that while, in

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general, the wind would be expected to increase with height, if $|\underline{V_G} - \underline{V_{10}}|$ were great enough there would likely be a layer with significant shear in it somewhere between 10 and 600 m. The lower limit was taken to be 40 kn for Rule 3 but 30 kn for Rule 4 which was otherwise the same except that it covered the case of an inversion or isothermal being present below 600 m. In either of these circumstances it would be likely that there would be a wind maximum somewhere below the level of the gradient wind which, therefore, would not need to be as strong.

2.3.4. The distinction between Rule 2 and Rules 3 and 4 with their respective conditions of V_{10} being greater than and less than 10 kn sometimes resulted in the decision to issue or not to issue a warning being far too critical and it was deemed necessary to remove these constraints for the summer trial. This was done in such a way that two rules were used in place of three and as will be seen from Appendix F, Rule 2 was dropped.

2.3.5. Rule 5 was concerned with shear arising from the proximity of cumulonimbus clouds and a distinction was drawn between those which were giving thunderstorms and those which were not. The greatest danger in respect of wind shear as is evidenced by such as both the Kennedy airport and Stapleton airport accidents is when an almost overhead cumulonimbus cloud is actually situated a short distance either upwind of the runway threshold for landing aircraft or downwind of the runway end for aircraft that are taking off. Both of these can create conditions of an increasing tailwind in circumstances in which the pilot might have neither enough height (if landing) or reserve power (if taking off) to be able to affect the necessary compensations. Nevertheless, the low level effects of downdraughts from a cumulonimbus cloud can be felt several miles away and in the winter trial this was reflected in the need to issue warnings whenever thunderstorms were thought to exist within 20 km (Rule 5a) and/or cumulonimbus clouds were known to exist within 10 km (Rule 5b) of the station. These distances resulted in far too many warnings being issued and so, as is seen in respect of the summer trial from Appendix F, they were halved to 10 km (Rule 5a) and 5 km (Rule 5b) and the added constraint was imposed that the cumulonimbus cloud should have a component of motion towards the station.

2.3.6. Rule 6, concerned with wind shear in relation to fronts had its origin in the results of investigations into aircraft accidents and incidents by Sowa (3). A distinction was drawn between fronts within 50 nm of the station

(a) having across them at the surface a vector wind change of at least 10 kn (Rule 6a)

and/or a 5°C temperature difference (Rule 6b)

or (b) moving at a speed of at least 30 kn (Rule 6c).

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These rules were tested solely in respect of fronts for the winter trial but for the summer trial the scope was extended to include other discontinuities such as squall lines and non-frontal troughs.

2.3.7. Rule 7 was concerned with low level jets, defined as a wind profile comprising 0-8 kn at the surface, increasing to 25-40 kn at 200-400 m and then decreasing with height to approach the gradient wind speed, typically 15-30 kn at about 600-900 m. Low level jets of this magnitude are almost exclusively a nocturnal phenomenon and have been observed to occur at Cardington, Bedfordshire, on average about one night in 50 although a weak form of the phenomenon (with an identifiable wind speed maximum at about 200-400 metres) occurs fairly frequently, on about one night in five, usually in association with a ground based inversion (4)

2.3.8. In applying Rule 7, a low level jet phenomenon was to be suspected if, at observation times between 2100 and 0600 GMT, all of the following criteria were satisfied:-

(1) the time was within the range sunset plus 3 hours to sunrise plus 1 hour.

(2) a ground-based inversion or isothermal layer was present and had been present for at least the preceding three observations and T_aT_a (max) minus T_aT_a was greater than 10°C. (See note below)

(3) V_{10} was less than 10 km and V_{10} (max) was $\geq$ 10 kn

(4) V_G was $\geq$10 km and V_G (sunset) was $\geq$10 km

(5) No surface front had passed through since 1200 GMT.

(Note:- V_{10} (max) and T_aT_a (max) are the maximum reported values of V_{10} and T_aT_a from 1300 to 1800 GMT inclusive during the previous afternoon)

2.3.9. A warning was to be issued under Rule 8 if an actual report of wind shear had been received from an aircraft, this being the strongest evidence of its existence that could become available.

2.4. Forecasters at the various met. offices were required to assess the need to issue a warning every hour that the station was operational with the aid, as in Appendices C and H, of a purposefully adapted FORTRAN code form on which the relevant parameters were logged, also every hour. The notation used is explained in Appendices B and G. Appendices C and H served the double purpose of providing the forecaster with the basic data required to decide upon the need to issue a warning and, by relating actual reports of wind shear, whether forecast or not, to these parameters, of being able to assess the usefulness of the rules.

2.5. Warnings issued took the form of either:

(a) WIND SHEAR EXPECTED BELOW 2,000 ft

or, if an actual report had been received from an aircraft

(b) WIND SHEAR EXPECTED AND REPORTED BELOW 2,000 ft

These messages in themselves give no indication of the intensity of shear

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expected or the reason for issuing a warning. Such reasons are important, however, so provision for this was included in the code for W as used in Appendices B and C and, in a different way, for W_1 and W_2 as in Appendices G and H.

2.6 Forecasters were advised that in cases of doubt arising from the non-availability of radar rendering it not possible to decide if thunderstorms and cumulonimbus clouds were near enough to the station to merit the issue of a warning under the appropriate rule, it was better to do so even though, overall, it would likely result in the issue of more warnings than necessary.

2.7 The only constraint placed upon the trials was that operational requirements would take priority at all times. It was realised that this would result in there being occasions when some requirement of the trial was not done and what would otherwise have been good wind shear days, being missed. There were a few such cases during the first trial and forecasters were asked, therefore, if rather than automatically not carry out some wind shear-related necessary task on such an occasion during the summer trial, they would first consider the matter together with other tasks on a locally determined priority basis.

2.8 Warnings arising from meteorological considerations were based on and issued with the H + 50 observation either on the appropriate form (F2309) or by closed circuit television. They were valid for one hour and this entailed their broadcast twice on any half-hourly broadcast (such as at H + 55 and H + 25 on A.T.I.S., the Air Traffic Information Service provided from some of the stations) or as appropriate on any other broadcast during the following hour. At those RAF stations where there is no such broadcast, warnings were passed to individual aircraft as necessary.

2.9 Aircraft reports became available in two ways. Firstly in real time by verbal communication between the pilot and Air Traffic Control from which the information was then passed to the local met. office and secondly, by subsequent written confirmation on Pilot Report Forms as shown in Appendices D and I. The sources of the verbal reports were not identified so it was not possible to correlate them with the written reports and although it was the intention that all of the former should be confirmed by the latter it was, perhaps, inevitable that there would be instances where this was not done.

2.10 To the extent that pilots might and likely would differ in their assessment of the intensity of any particular case of wind shear and the aircraft handling difficulties it presented to them, aircraft reports are subjective. Aircraft flight records, on the other hand, are objective within the limits of the accuracy and reliability of the instrumentation used to obtain them. Not all aircraft that took part in the trials were equipped with the means to provide flight records and of those that were, the

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instrumentation differed to some extent between aircraft types. The greatest numbers of flight records capable of yielding changes in headwind components were obtained from such civil aircraft as Tridents, Tristars, BAC 111s and most of the B747s. A smaller number of B747s and the Concordes are fitted with an Inertial Navigation System (INS) from which it is possible to compute wind directly. On the RAF side, the INS fitted to the Nimrods of St. Mawgan and Kinloss provided a direct readout of wind but from the other RAF aircraft taking part in the trials there were no flight records whatsoever. Those that are available come from some 900 or so flights but it seems likely that their analysis will be protracted. This is largely because it has not been possible to account for serious inconsistencies which have been thrown up by the computer in its handling of some of the flights but will not be further elaborated upon here. For that reason, this paper is concerned with analysis of the pilots' reports only.

2.11 The success of a warning, concerned more for this investigation with the adequacy of the meteorological rules to predict shear at all rather than their consequential usefulness in enabling a pilot to take effective action, was assessed in the light of the aircraft reports received. In the analysis of these it was assumed that all those of positive shear were correct even though at about the same time there might have been conflicting reports of 'No Shear'. Such conflict was not disputed but regarded rather as evidence of a variability in the dimensions of the affected areas which renders wind shear the more difficult to forecast and detect. Most of the aircraft reports by being substantiated in writing provided, among other comments, such details as aircraft height, shear intensity and the resulting change of airspeed. They were considered to be more reliable than those which were not confirmed in writing and for which such details were generally not available. Within this constraint a warning was considered to have come within the categories (1) successful (2) probably successful (3) probably unsuccessful and (4) unsuccessful if a written aircraft report indicated that shear had been experienced within 1, 2, 3 or more than 3 hours respectively before its time of issue. A warning issued after receipt of an aircraft report was considered to have been less successful than one issued before and both this and the lesser reliability attributed to the purely verbal reports were taken into account in the Success Plan shown in Appendix E.

3. THE DATA AVAILABLE

3.1 As indicated in Section 2 above, data became available as follows:-

(a) on forms such as those shown in Appendices C and H on which they were logged hourly throughout those parts of the trial that the station was operational

(i) a code figure showing whether or not a warning had been issued and if so, the Rule(s) as given in Appendices A and E under which

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it was done

(ii) the values of parameters which, in the main, were those relevant to the wind shear warning rules but there were a few others, not so used, the possible relevance to low level wind shear of which was being looked into. Full lists of these parameters and their meanings are given in Appendices B and C.

(b) On Pilot Report Forms such as those shown in Appendices D and I. These forms provided not only for the reporting of wind shear in terms of its height of occurrence and the symptoms used to recognise it but also for any consequential difficulties in handling the aircraft and action taken to help alleviate them.

3.2. Further to 3.1.(a) and 3.1.(b) above, Appendices J and K give the following statistics separately for each station and as totals, both separately and combined, for all the RAF and civil stations involved in the two trials:-

(i) Date trial commenced

(ii) Number of days station was involved in the trial

(iii) Number of hours station was involved in the trial

(iv) Numbers of reasons, separately and in toto, why warnings could have been issued under the meteorological rules 1-7

(v) Total numbers of warnings that were issued under rules 1-7

(vi) Numbers of warnings issued under rule 8 - i.e. purely as a result of the receipt of an aircraft report of positive shear

(vii) Total numbers of reasons why warnings could have been issued under any of the rules 1-8

(viii) Total numbers of warnings that should have been issued

(ix) Total numbers of warnings that were issued

(x) Percentage of time that warnings should have been in force

(xi) Numbers of aircraft reports received

(xii) Numbers of (a) slight (b) moderate (c) severe reports of shear received

(xiii) Total numbers of positive reports of shear received

(xiv) Numbers of negative reports on days when warnings were issued

3.3. The figures in Appendices J and K for the winter and summer trials respectively enable comparisons to be made between different civil stations, different RAF stations and between totals for all civil and all RAF stations.

3.3.1. Winter Trial - Appendix J

The variation in the numbers of reasons why warnings could have been issued is clearly seen from Row 4. In some cases there were considerable differences between stations as for example rule 7 under which there were 16 occasions when Glasgow had cause to issue a warning while London and Birmingham had none. Again, under rule 3, Glasgow issued

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a warning on 35 occasions but London could do so only twice and neither Birmingham nor any of the RAF stations could do so at all. There is thus an impression that some stations more than others over-responded or under-responded to certain rules but such differences could well be real. Another feature of Appendix J (Row 9) is that the 3 civil stations issued more warnings (606) than the 6 RAF stations (402) even though they were operational for less time (6984 compared with 8450 hours - see Row 3). The corresponding numbers of warnings that should have been issued for meteorological reasons only are seen from Row 5 to be 526 and 385. It is not thought that the reasons for such differences are mainly meteorological but even if they were they are not of such an order of magnitude as to merit an in-depth investigation. It is sufficient to note from column 12 that for all stations combined there were 1113 meteorological reasons why 911 warnings were issued and a further 167 reasons when issue was merited because of the receipt of aircraft reports. In toto there were 1280 reasons why 1071 warnings should have been issued but for various reasons, principally human error, involving warnings both wrongfully issued and wrongfully not issued, the actual number issued was 1008. These figures are largely reflected in the corresponding totals for the civil and RAF stations in cols 4 and 11 respectively and it is in both these and more particularly the figures of col 12 that the real value of Appendix J lies. From Row 4 of col 12 it will be seen that, to varying degrees, warnings were issued for all of the meteorological reasons from which the rules were devised and from Row 10 of col 12 it will be seen that they were in force for about 7 per cent of the time. It had originally been thought that warnings would have been in force for about one per cent of the time and, as will be seen later from the figures on success in section 4(a), this was probably about right. It appeared that the rules used for the winter trial allowed of considerable over-warning and from col 12 it will be seen that while this was due moreso to rules 5b, 6a and 6c than to others, it could, nevertheless have been due to a smaller extent to other rules as well.

3.3.2. Summer Trial - Appendix K

3.3.2.1. In an attempt to deal with the problem of over-warning, rules 5a, 5b and 6c were, for the summer trial, modified with the result, as is seen from Row 10, Col 14 of Appendix K, that warnings were in force for only 2.3 per cent of the time. To some extent the drop from 7 to 2.3 per cent reflects a real change between the need to issue warnings in winter and summer but even the latter figure is high compared with the 1 per cent that was expected.

3.3.2.2. As for the winter trial, the greater number of warnings (187) issued in a smaller number of hours (6624) by the civil stations than the RAF stations (132 in 10,383 hours) is again evident but not thought to be of meteorological significance. No warnings whatsoever were issued under rule 6b and only one station (Kinloss) issued warnings under rule 1. Otherwise, as in Appendix J,

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warnings were issued under all the rules. It will be seen from col 14 that there were 432 meteorological reasons why 351 warnings were issued and cause for a further 45 warnings to be issued because of the receipt of aircraft reports. In all, 387 warnings should have been issued but for the same reasons as given in para 3.3.1. above in respect of Appendix J, the actual number issued was 319.

3.3.3. BOTH TRIALS

3.3.3.1. Rows 11 of both Appendices J and K give the numbers of written aircraft reports received during the two trials. In the main, positive reports of shear were in respect of periods when warnings were in force but there were a number, considered later in section 4c when this was not so. The numbers of positive reports of shear are subdivided into slight, moderate and severe in Rows 12(a), (b) and (c) respectively and these are totalled in Row 13. The numbers of negative reports of shear are given in Row 14. It will be seen from cols 12 and 14 respectively that:

(i) there were about half as many aircraft reports received as warnings issued (552 reports and 1008 warnings in the winter trial - Appendix J - and 161 reports and 319 warnings for the summer trial - Appendix K)

(ii) the total numbers of positive and negative reports were about the same (273 positive and 279 negative for the winter trial (Appendix J) and 84 positive and 77 negative for the summer trial (Appendix K)

(iii) there were more reports of moderate shear than slight shear (151 moderate against 107 slight - Appendix J - and 46 moderate against 38 - Appendix K - for both trials

(iv) whereas for the winter trial there were 15 reports of 'Severe' shear, there were none in the summer trial. This could be considered to suggest that severe shear would not normally occur in summer in the United Kingdom other than in association with thunderstorms.

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4. Analysis of the Data

4.1. The main part of the analysis entailed the preparation of monthly tables which showed

(i) by station for all (meteorological) rules - i.e. excluding rule 8

(ii) by rule for all stations

the numbers of warnings to which it was or was not possible to allocate a success category. These have been combined into the composite Tables A and B shown in Appendices L and M. Other meteorological investigations concerned the conditions under which shear, for whatever reason, was regarded as severe, was reported as having occurred when no forecast or warning had been issued and any relationship that might exist between shear and gradient wind and between gradient wind and gust speeds at the 10 metre level. In addition, the opportunity was taken to look into the susceptibility to wind shear of different types of aircraft, the comments of pilots on how they recognised shear and the aircraft handling difficulties it caused. The full list of investigations carried out concerned the following:-

	Para.
(a) Overall success of the warning scheme	4.2
(b) Cases of 'Severe' wind shear	4.3
(c) Reports of wind shear when no warning had been issued	4.4
(d) Wind shear in relation to surface and gradient wind	4.5
(e) Wind shear in relation to gust speeds at the surface	4.5
(f) Severity of wind shear in relation to aircraft type	4.6
(g) Detection of wind shear arising from changes in ground speed	4.7
(h) Detection of wind shear arising from changes in drift	4.8
(i) Reports of turbulence in association with wind shear	4.9
(j) The possibility of wind shear arising from the proximity of such as aircraft hangars	4.10
(k) Aircraft handling difficulties arising from wind shear	4.11
(l) Comments by pilots other than those in (f) - (k) above	4.12
(m) Numbers of aircraft movements	

These are considered separately below.

4.2. Overall Success of the Warning Scheme

It was often possible to issue a warning for more than one rule and where such a warning was successful it would not be known to which rule credit should be allocated. The problem was dealt with by accrediting each with a success of $\frac{1}{x}$ where x was the number of rules. These did not exceed 3 so that fractions of $\frac{1}{2}$ and $\frac{1}{3}$ and consequently $\frac{1}{6}$ and $\frac{5}{6}$ appear in the Tables below in respect of the numbers of successes credited to the various rules.

4.2.1. It will be seen from col 12 of Appendix L (Winter Trial) that

(i) out of 911 warnings that should have been issued from 1113 purely meteorological

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reasons, it was possible from aircraft reports received to assign a success category to 367 of them but, due to the absence of aircraft reports, it was not possible to reach any conclusion about the remaining 544. (It had been hoped that, to a large extent, particularly in respect of those issued from the civil stations, analysis of the flight records would have eventually remedied this but the latter were too unreliable)

(ii) of the 367 warnings referred to in (i) above, it was considered that 111 were successful, 54 were probably successful, 41 were probably unsuccessful and 161 were unsuccessful.

(iii) warnings could have been issued under all the rules but because some were issued for more than one reason it was not possible accurately to identify each of the 911 warnings with a single rule. However, out of the 1113 reasons why the warnings could have been issued, the greatest numbers were 461, 226 and 153 under Rules 5b, 6a and 6c respectively. The smallest numbers were 7 under both Rules 1 and 6b. These figures are given in the Table below.

(iv) the ratio of the numbers of successful warnings to the total number about which it was possible to assign any success category was $\frac{111}{367} = 0.30$. The extent to which this is reflected individually for the rules, the numbers of successful warnings under which have been converted to percentages of the total is shown below (row f):-

	RULE										Total Nos. of	
	1	2	3	4	5a	5b	6a	6b	6c	7	Reasons	Warnings
(a) Nos. of Reasons why Warnings were issued under Rules 1-7	7	75	37	83	32	461	226	7	153	32	1113	911
(b) No. with any Success Category	3	$25\frac{5}{6}$	$14\frac{2}{3}$	$39\frac{1}{3}$	$7\frac{1}{2}$	$147\frac{1}{6}$	$66\frac{5}{6}$	$\frac{5}{6}$	$53\frac{5}{6}$	8	367	367
(c) Nos. Successful	1	$6\frac{5}{6}$	$2\frac{1}{3}$	4	3	51	$20\frac{1}{6}$	$\frac{1}{3}$	$19\frac{1}{3}$	3	111	111
(d) (c) as % of (a)	14.3	9.1	6.3	4.8	9.4	11.1	8.9	4.8	12.6	9.4	10.0	12.2
(e) Ratio $\frac{(c)}{(b)}$	0.33	0.26	0.15	0.10	0.4	0.34	0.30	0.39	0.35	0.37	0.30	0.30
(f) (c) as % of its total of 111	0.9	6.1	2.1	3.6	2.7	45.9	18.2	0.3	17.4	2.7	99.9	

Clearly the greatest significance attaches to Rules 5b, 6a and 6c for which, with success ratios of 0.34, 0.30 and 0.35, there were the greatest percentages of the total numbers of successes (45.9, 18.2 and 17.4 respectively)

4.2.2. It is seen from col 14 of Appendix M (Summer Trial) that

(i) out of 351 warnings that were issued from 432 meteorological reasons it was possible from aircraft reports received to assign a success category to 83 of them but, due to the absence of aircraft reports, it was not possible to reach any conclusion about the remaining 268. Here again, it has been hoped → but in vain ← that analysis of the flight records would have eventually remedied this.

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(ii) of the 83 warnings referred to in (1) above, 26 were considered to have been successful, 15 were probably successful, 12 were probably unsuccessful and 30 were unsuccessful.

(iii) warnings could have been issued under all the rules but because some were issued for more than one reason it was not possible accurately to identify each of the 351 warnings with a single rule. However, out of the 432 reasons why warnings could have been issued, the greatest numbers were 140, 86 and 54 under Rules 6a, 5b and 6c respectively. These are the same 3 as for the winter trial but for that there were more cases under 5b than 6a.

(iv) there were smaller though significant numbers under Rules 3, 4, 5a and 7 - viz 44, 16, 36 and 48 respectively.

(v) the smallest numbers were 0 and 8 under Rules 6b and 1 - the same two as for the winter trial.

(vi) the ratio of the numbers of successful warnings to the total number about which it was possible to assign any success category was $\frac{26}{83} = 0.31$ (which compares with 0.30 for the winter trial). The extent to which this is reflected individually for the rules, the numbers of successful warnings under which have converted to percentages of the total is shown below in row f.

	RULE 1	2	3	4	5a	5b	6a	6b	6c	7	Total Nos. of Reasons	Total Nos. of Warnings
(a) Total Nos. of Reasons why Warnings were issued under Rules 1-7	8	Not Used	44	16	36	86	140	0	54	48	432	351
(b) No. with any Success Category	3	" "	$22\frac{5}{6}$	$3\frac{1}{3}$	$6\frac{1}{2}$	$13\frac{5}{6}$	$18\frac{1}{2}$	0	10	5	83	83
(c) Nos. Successful	0	" "	$11\frac{1}{2}$	$1\frac{1}{2}$	$2\frac{1}{2}$	3	$3\frac{1}{2}$	0	3	1	26	26
(d) (c) as % of (a)	0	" "	26.1	9.4	6.9	3.5	2.5	0	5.5	2.1	6.0	7.4
(e) Ratio $\frac{(c)}{(b)}$	0	" "	0.50	0.45	0.38	0.22	0.19	0	0.30	0.20	0.31	0.31
(f) (c) as % of its Total of 26	0	" "	44.2	5.8	9.6	11.5	13.5	0	11.5	3.9	100.0	

From this Table, the greatest significance will be seen to attach to Rule 3 for which, with a success ratio of 0.50, there was the greatest percentage (44.2) of the total number of successes. Rules 5b, 6a and 6c have the next greatest percentages of successful warnings (11.5, 13.5 and 11.5 respectively) but with lower ratios in row (e) of the summer Table than of the winter Table, they lose some of their significance. Indeed, Rules 4 and 5a with success percentages of 5.8 and 9.6 (Row (f)) assume greater significance because of the higher ratios (0.45 and 0.38) but against this, there were only $1\frac{1}{2}$ and $2\frac{1}{2}$ successes respectively out of a total of 26. Rule 6c with a success percentage of 11.5 and a ratio of 0.30 is not very different from its corresponding significance in the winter trial.

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4.3 Cases of 'Severe' Wind Shear

4.3.1. Winter Trial

4.3.1.1. Subjectiveness in assessing the severity of shear is evident from all the aircraft reports received. Considering only the 15 reports of 'Severe' shear received during the winter trial, the numbers involving airspeed increases or decreases can conveniently be divided into ranges of airspeed changes as follows:-

Change in Airspeed (kn)	No. of cases
Less than 10	1
10–19	6
≥ 20	7
Airspeed change not given	1
Total	15

It will be seen that for one of the reports the airspeed change was less than 10 kn. This was a report of both increases and decreases of only 8 kn and as such is thought really to have been turbulence rather than shear. If, however, shear had been involved, its intensity is unlikely to have been more than slight. Six of the reports (including one of 15–20 kn) were associated with airspeed changes in the range 10–19 kn, seven were of changes ≥ 20 kn and for one report the magnitude of the change was not given. For 13 of the 15 reports, therefore, pilots could be divided between those who regard 'severe' shear to be associated with airspeed changes in excess of 10 kn and those for whom the lower limit is 20 kn. It would seem from considerations such as these that a reasonable and practical interpretation of shear intensity would be

'Slight' for airspeed changes of less than 10 kn
'Moderate" " " " " between 10 and 19 kn
'Severe' " " " " 20 kn or more

With this classification, the number of so-called 'severe' reports is reduced to 7. There were, however, 18 additional reports of airspeed changes of 20 kn or more for which the shear intensity was not described as severe. Of these, 15 and 2 were associated with what was described as moderate and slight shear respectively and for the remaining one the shear intensity was not given. There were thus a total of 25 (18 + 7) cases of shear within the above interpretation and they are included as the third line of the Table in Appendix N, in which are combined all 33 reports of shear which were either described as severe (15) or were associated with airspeed changes of 20 kn or more (18). In this Table, the reports are further divided between several convenient height bands and also according as the airspeed change was an increase, a decrease or both.

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4.3.1.2. It will be seen from the totals in the extreme right hand column of the Table in Appen. N that 25 of the 33 reports were in respect of airspeed changes which were reported by pilots to be of 20 kn or more. Of these, 20, 15 and 5 occurred at or below heights of 1,000, 600 and 200 ft respectively. Inasmuch as half (10) of these occurred in the height band 200-600 ft, there is a suggestion that this could be a band for which low level shear is more prone and to which, perhaps, greater attention should be paid when considering the issue of a warning.

The largest airspeed change given was 40 kn but the report is ambiguous in that, unlike other reports, it is not stated whether it was an increase or decrease and the height of occurrence is given only vaguely as below 2,000 ft. There was another otherwise identical report except that the airspeed change was 30 kn. The highest specific report was of an airspeed increase of 32 kn at 400 ft. It was described as 'moderate' but within the above interpretation would have been regarded as 'severe'. There were 5 other reports of an airspeed change within a range, the upper limit of which was 30 kn and of these, 2 occurred at heights below 300 ft. These reports could be considered to provide acceptable evidence that severe shear causing airspeed changes of up to at least 32 kn can occur at heights below 400 ft.

4.3.1.3. Of the 33 reports, 31 were from civil aircraft. The remaining 2 were from Victor aircraft of RAF Marham. Of these two, one was that referred to above in which the airspeed change amounted to no more than a fluctuation of $\pm$ 8 kn and was more probably a case of turbulence associated with no more than slight, if any, shear. The other also involved positive and negative changes in airspeed but they were unequal, the largest being a positive change of 30 kn and the height of occurrence was 900 ft. With the possible exception of Victor aircraft, therefore, there is a suggestion that RAF aircraft are not as prone to relatively sudden airspeed changes exceeding 20 kn as are civil aircraft when flying in similar conditions. However, there could be other reasons for the difference - e.g. many more civil than RAF aircraft flying, RAF aircraft tending not to fly in conditions likely to produce shear and perhaps, even, less enthusiasm on the part of the RAF pilots in making reports. The winter trial did, in fact, produce evidence of this latter possibility.

4.3.1.4. The 33 reports either classified by pilots as 'severe' or involving airspeed changes of 20 kn or more were made on 19 different days. If all those made at heights above 1,000 ft and those of the pilots' reports for which the airspeed change was less than 20 kn be excluded, they reduce to 20 cases in 14 days. The relevant synoptic charts were examined in each of these to see if any relationship could be found between them and the synoptic situation in terms of pressure systems, fronts and troughs and wind. Nineteen of the 20 cases involved reports from civil aircraft and the other was from a military aircraft.

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4.3.1.5. In 17 of the 20 cases the nearest pressure system was a depression but in the remaining 3 it was an anticyclone. Distances of the centres of the depressions from the station ranged from less than 100nm to over 1,000 nm and the speed of movement ranged from 'slow' to 50 kn.

The distance of the nearest front or other discontinuity from the station varied from a few nm to over 200nm. There were each cases of when the nearest was a warm or cold front, occlusion and trough. On some occasions it had passed through the station while on others it was still to come. In 10 of the 20 cases the station was near enough for it to have been possible to measure both the surface shear and surface temperature change across the front and of these, 7 involved cold fronts. While respective changes were as high as 20-25 kn and $\pm$ 3°C, there were others in the ranges 0-5 kn and $\pm$ 1°C, values too small for these parameters to be useful as indicators of not only severe, but any intensity of shear.

Wind speed, likewise, did not exhibit any relationship, surface values ranging from less than 10 kn to 30 kn and gradient values, while all being greater than 20 kt, ranging upwards to between 70 and 80 kn. Wind directions, however, appeared to show a higher association in that they were between 135 and 270 degs in 16 of the 20 surface wind cases and 17 of the gradient wind cases. In 13 of each of these, surface wind direction was between 180 and 225 degs and gradient wind direction was between 225 and 270 degs. Such relationships as these were also found in connection with intensities of shear less than 'severe' and they may well amount to no more than a reflection of the prevailing wind conditions throughout the trial. All things considered, these investigations into pressure systems, fronts and winds produced nothing positive but there are suggestions, albeit inconclusive, that where severe shear is concerned, cold fronts are more important than other fronts and that wind direction may have a relevance.

4.3.2. Summer Trial

There were no pilots' reports of severe wind shear as such during the summer trial. There were, however, 4 reports on 3 separate days when the airspeed change was equal to or exceeded 20 kn and of these, only one, at 300 ft occurred at a height below 1,000 ft. All 4 reports came from civil aircraft, in each case the pilot had described the shear as moderate and in none of them was any aircraft handling difficulty reported. In that there were no similar reports from RAF aircraft, these cases could, but to a lesser extent than in the winter trial because there are so few of them, again constitute tenative evidence that civil aircraft are more prone to airspeed changes exceeding 20 kt than RAF aircraft flying in similar conditions. However, as there was only one of these reports in respect of a height below 1,000 ft (compared with 20 in 14 days for the winter trial) no statistical analysis is possible and no positive conclusion either can be reached or should even be hinted at.

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4.4 Reports of Wind Shear when no warning had been issued

4.4.1. The issue of a warning of wind shear is a spur to encourage pilots to report on its occurrence or non-occurrence moreso than to report on its occurrence when no warning had been issued. Nevertheless, pilots were asked to do both and of the 167 aircraft reports received during the winter trial, 78 were in respect of occasions when it appeared that no warning had been issued. This was subsequently found not to be so in some instances but 62 of these reports covering 52 separate periods seemed justified. They were made over 32 dates on 44 occasions distributed between the participating stations as follows:-

Station	No. of Days
Glasgow	5
Birmingham	9
London	15
Brize Norton	2
Honington	1
Marham	5
Scampton	1
Waddington	1
Wyton	5
Total	44

The method of investigating these was to see if, notwithstanding the evidence available from the forms filled in at the station met. offices, there could have been any reasons, meteorological or otherwise, that could have been considered to have been the cause or part of the cause of what was reported by the pilots as wind shear. To this end, investigations were carried out in respect of:

(a) the proximity and speed of movement of pressure centres
(b) the type, proximity and speed of movement of fronts or other discontinuities
(c) the gradient wind speed and direction
(d) the surface wind speed and direction
(e) the lowest levels of the relevant radio-sonde ascents.

4.4.2. Winter Trial

4.4.2.1. Pressure Centres

On occasions when the value of the central pressure of the nearest depression or anticyclone lay within 10 mb ranges between 960 and 1039 mb, reports of slight, moderate and severe wind shear were related to the speed of movement of the centre and its proximity to the station from which the aircraft report originated.

For 50 of the 62 reports in the 52 separate periods referred to above it was possible to identify and measure a speed of movement of pressure centres and it was found that

(a) of the associated reports, 13 were of slight, 32 were of moderate and 5 were of severe shear

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(b) 42 of the 50 reports were associated with depressions having central pressures of less than 1,000 mb

(c) there were no reports of severe shear associated with pressure systems having central pressures of 990 mb or more and the centres of which were located 200 nm or more from the station

(d) reports were received on occasions when the speed of the centre varied between 'slow' and 50 kn and the distance of the centre from the station varied from between 50 and 100 nm to over 1,000 nm

(e) there were 5 cases of slight or moderate shear associated with anticyclones having central pressures between 1030 and 1039 mb

(f) for pressures between 1,000 and 1,030 mb there were a total of only 3 cases consisting of 2 reports of moderate shear for central pressures between 1,000 and 1,009 mb and one report of slight shear for a central pressure between 1020 and 1029 mb. For central pressures between 1010 and 1019 mb there were no reports.

4.4.2.2. Fronts

There were reports of slight, moderate and severe shear in association with each of warm, cold and occluded fronts and troughs. The greater number of reports were associated with fronts that were 'to come' as opposed to those that had passed through the station in the cases of warm (14 to 4) and cold (8 to 4) fronts but for occlusions (10 to 2) most of the reports were associated with fronts that had passed. For troughs it did not seem to matter much whether they were to come or had passed (3 to 4). The numbers of reports were fairly evenly distributed between the fronts, being 14, 18 and 12 for cold, warm and occluded fronts respectively.

In respect of speed of movement, reports were received in association with fronts moving as slowly as less than 10 kn and at distances from the station of over 500 nm in the case of warm fronts but otherwise of up to 400 nm.

4.4.2.3. Wind

4.4.2.3.1. Gradient Wind

There were no reports in the direction ranges 91-135 and 316-360 degs and only one (of slight shear) in the range 0-45 degs. 47 of the 52 periods were in the 180 deg range 136-315 with 34 of them between 180 and 270 degs. There were no reports in the speed range 0-9 kn, otherwise there were reports in association with speeds in all 10 kn ranges from 10 to 79 kn.

4.4.2.3.2. Surface Wind

There were no reports of shear with directions in the range 316-360 degs and a total of only 7 in the range 0-135 degs. 43 of the 52 reports were in the range 136 - 270 degs. The remaining 2 were in the range 271 - 315 degs. In respect of speed, there were cases in association with all 10 kn ranges from 0 to 39 kn.

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4.4.2.4. Radio-Sonde Ascents

4.4.2.4.1. Values of Shears based on the lowest reported two winds - viz the 10 m wind and the next lowest, regardless of its height, were found as follows:-

Kn / 100 ft

	-0.5 to 0	0.01-0.5	0.51-1.0	1.01-1.5	1.51-2.0	2.01-2.5	2.51-3.0	Total
No. of cases	1	22	16	7	5	0	2	53+

4.4.2.4.2 Values of Temperature Lapse based on the two lowest reported temperatures - viz the 10 m temperature and the next lowest reported were found as follows:-

°C / 100 ft

	-0.5 to -0.26	-0.25 to 0	0.01-0.25	0.26-0.5	0.51-0.75	0.76-1.0	Total
No. of cases	1	2	20	22	5	5	55+

+ Note There were 52 cases under consideration. For some of these more than one R/S ascent was relevant and 55 were looked at. In 2 of these no winds were reported , no shears could therefore be computed and the total in 4.4.2.4.1. is reduced to 53.

4.4.2.4.3. Comment

4.4.2.4.3.1. Re Values of Wind Shear

The largest computable value was in the range 2.5-3.0 kn/100 ft. The associated aircraft reports were of moderate shear in both cases. The speed changes were given as a decrease of 7 kn in airspeed corresponding to a computed shear of 2.5 kn /100 ft and an increase of 30 kn in groundspeed corresponding to a computed shear of 2.8 kn / 100 ft. Otherwise, changes did not exceed 2.0 kn/100 ft and of the remaining 51, 50 were in the range 0-2 kn/100 ft , the final one being in the range 0 to -o.5 kn/100 ft. These changes were based on wind differences over height intervals which in some cases were as large as several thousands of feet so they would not preclude the possibility, indeed liklihood, of larger values over smaller height intervals. However, we have no real means of knowing this.

4.4.2.4.3.2. Re Values of Temperature Lapse Rate

The largest values were in the range 0.76 - 1.0°C per 100 ft. Three values were negative, one being in the range -o.5 to -0.26°C/100 ft and 42 of the values were between 0 and 0.5°C / 100 ft. Temperature lapse rates such as these could be expected at any time and there would not seem to be anything that would mark out these occasions as ones in which shear would unexpectedly occur.

The conclusion to be drawn from the radio-sonde ascents, therefore, is that they contribute nothing positive to the search for reasons why shear was unexpectedly reported on these occasions.

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4.4.3. Summer Trial

4.4.3.1. Pressure Centres

For the summer trial there was a significantly higher proportion of aircraft reports of shear on occasions when no warning had been issued than for the winter trial. (49 reports outof 161 covering 45 periods on 33 dates compared with 78 reports out of 552 covering 52 periods on 32 dates. It was found that:

(a) of the 49 periods, 25 involved reports of slight and 24 of moderate shear. There were no reports of severe shear.

(b) 27 of the 49 were associated with systems having central pressures of less than 1000 mb. This is a much smaller proportion than the 42 out of 50 for the winter trial.

(c) reports were received on occasions when the speed of the centre varied between 'slow' and over 50 km (70 kn on one occasion) and the distance of the centre from the station varied from 30 nm to over 1,000 nm.

(d) there were 6 cases of slight or moderate shear associated with anticyclones having central pressures of between 1030 and 1039 mb - much the same as for the winter trial.

4.4.3.2. Fronts

There were reports of slight and moderate shear in association with cold, warm and occluded fronts but only 3 reports of slight shear and no reports of moderate shear associated with troughs. There were no reports of severe shear.

Altogether there were about equal numbers both of reports of slight and moderate shear (25 to 24) and of fronts 'to come' as opposed to those that had passed through the station (24 to 25).

In respect of speed of movement, reports were received in association with fronts moving as slowly as less than 10 kt and at distances of up to over 500 nm.

4.4.3.3. Wind

4.4.3.3.1. Gradient Wind

There were no reports of slight shear with wind directions in the quadrant 136-225 degs, otherwise there were reports of slight and moderate shear in all quadrants with the greatest numbers between 0 and 90 degs (15 total) and 226-315 degs (19 total). 34 of the 49 were thus in these two quadrants and the remaining 15 were shared between the other two. One report of moderate shear was associated with a gradient wind speed of less than 10 kn, otherwise there were reports in association with speeds in all 10 kn ranges from 10 to 49 kn.

4.4.3.3.2. Surface Wind

There were reports with wind directions in all quadrants but only of moderate shear with wind directions between 90 and 180 degs. 17 were with directions

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between 0 and 90 degs and 25 were with directions between 180 and 315 degs. The remaining 7 were with wind directions between 90 and 180 and between 316 and 360 degs. There were reports with wind speeds in all 10 kt ranges from 0 to 30 kt.

4.4.3.4. Radio-Sonde Ascents

4.4.3.4.1. Values of Shears based on the lowest reported two winds (as in 4.4.2.4.1.)

Kn / 100 ft

	-0.5 to 0	0.01-0.5	0.51-1.0	1.01-1.5	1.51-2.0	2.01-2.5	2.51-3.0	Total
No. of Cases	4	18	10	6	5	0	0	43

4.4.3.4.2. Values of Temperature Lapse based on the two lowest reported temperatures (as in 4.4.2.4.2.)

^{o}C / 100 ft

	-0.5 to -0.26	-0.25 to 0	0.01-0.25	0.26-0.5	0.51-0.75	0.76-1.0	1.01-1.25
No. of Cases	0	3	5	11	12	8	2

contd

continuation of Table...	1.26-1.5	2.01-2.25^{o}C	Total
No. of Cases	1	1	43

There were 43 ascents under consideration representing 49 cases. For none of these was more than one ascent deemed necessary to plot and consider.

4.4.3.4.3 Comment

4.4.3.4.3.1. Re Values of Shear

The largest computable value was in the range 1.51-2.0 kn/100 ft and there were 5 of these. For 4 ofthem the shear was reported as moderate and for the other one it was reported as very slight. For 4 of these (including the 'Very Slight') there was a decrease in airspeed of up to 15 kn. For the fifth, the change in airspeed was not recorded either in magnitude or as an increase or decrease. Otherwise, there were changes in all 0.5 ranges from-0.5 to +1.5 kn / 100 ft. The greatest number was 18 and it was in the range 0.01 -0.5 kn/ 100 ft.

4.4.3.4.3.2. Re Values of Temperature Lapse

The largest value was 2.17^{o}C / 100 ft. It was associated with slight shear which was reported at 100 ft. There was also one value in the range 1.26 - 1.5^{o}C/100 ft. Otherwise, the largest values were in the range 1.01 - 1.25 and there were two of them associated with 3 reports. Two of these reports were associated with slight shear and the third was with moderate shear. All 3 were associated with decreases in airspeed.

Otherwise all changes were in the range-0.25 to +1.25^{o}C/100 ft. Temperature lapses such as these could be expected at any time and there would not seem to be anything that would mark out these occasions as ones in which shear would unexpectedly occur.

As was the case from the corresponding investigation from the winter trial, it is concluded that the R/S ascents contributed nothing positive to the search for reasons why shear was unexpectedly reported on these occasions.

4.5. Wind Shear in Relation to Surface and Gradient Wind

4.5.1. Among the parameters logged hourly on the forms at the participating outstation met. offices were:

ddff - the direction and speed of the surface wind

$f_g f_g$ - the speed of the maximum surface gust (in the last 10 minutes for the winter trial, in the last hour for the summer trial)

$D_G D_G f_G f_G$ - the direction and speed of the gradient wind.

As explained in section 2.11 above, warnings issued were classified as 'successful', 'probably successful', 'probably unsuccessful' and 'unsuccessful' and the above parameters were considered separately in the light of each of these. The more important relationships were between 'successful' and 'unsuccessful' warnings and the purpose of the investigation was to see if there were any significant differences between any relationships that might exist between them. The absence of any relationship at all or the absence of any such difference would mean that the parameter in question would be of no value as a guide to the liklihood of wind shear - even assuming that the parameter was forecastable.

4.5.2. Graphs were plotted for all intensities of shear, in respect of both written and unwritten reports and for each of the 4 success categories of

(i) $f_g f_g$ against ff and

(ii) $f_g f_g$ against $f_G f_G$

4.5.2.1. Graphs of $f_g f_g$ against ff

The slopes of the graphs for each of the 4 success categories were all about 1.43 and the scatter of points on the different graphs was much the same. A feature of the Category 1 (Successful) graph was that there were no reports of shear at all for $f_g f_g$ les than 14 kn and ff less than 8 kn. The lowest valuesfor a report of severe shear were 13 kn for ff and 16 kn for $f_g f_g$.

4.5.2.2. Graphs of $f_g f_g$ against $f_G f_G$

The essential difference between these and the graphs of $f_g f_g$ against ff is the very wide scatter. It was not thought necessary to carry out a 'least squares' analysis to obtain the best straight line and was deemed sufficient to note whether or not the graphs exhibited any significant features. The following figures give the lower for each of the parameters for cases of 'severe' shear:-

Success Category		$f_g f_g$ kn	$f_G f_G$ kn
Successful	1	15	35 but there were only 6 values
Probably Successful	2	20	40 " " " " 3 "
Probably Unsuccessful	3	10	24 " " " " 2 "
Unsuccessful	4	5	38 " " " " 2 "

It is suggested that to take the lower limits of $f_g f_g$ and $f_G f_G$ to be

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15 and 35 kn respectively will give a guide line on whether severe shear could be forecast but it will not guarantee that the forecast would be correct.

The slope of each of these graphs was judged to be about 0.83 but there was a wide scatter.

One other feature noticed - from the graph for Success category 1 - was that no shear warning of any intensity is likely to be successful if surface wind gusts of less than 12 kn are expected and it is suggested that in such circumstances, no such warning should be issued.

4.5.2.3. Other graphs plotted were of height of occurrence of wind shear against associated increase and decrease of airspeed for each success category

(i) for all the rules combined

(ii) for rules 5a and 5b combined

(iii) for rule 6a

(iv) for rule 6c

(v) for combined rules other than 5a, 5b, 6a and 6c

Where it was reported, the accompanying height change arising from the shear was indicated against the plotted value by the letters D (decrease in height), I (increase in height) and N (no accompanying change in height). Comments from an inspection of the Success Category 1 graphs are as follows:-

Rule 1 - there was only one instance of shear having been considered to have been successfully forecast. However, the airspeed changes associated with it were both positive and negative and it suggests that it was not a case of true shear in the sense of a sustained wind change. Fluctuating wind changes at a particular height (700 ft in this case) would be largely self-cancelling and the net effect on the aircraft would be small.

Rule 2 this was successful at heights from 1800 ft down to 200 ft and the maximum shear associated with one of the warnings resulted in an airspeed change of 25 kn at 500 ft. Altogether there were a total of 13 cases of which 3 involved fluctuations of speed (and for the reason given under Rule 1 above was not regarded as true shear). Of the remaining 10, 6 were of a decrease and 4 were of an increase in airspeed. Of the 4, one was associated with an increase in height while the others either did not specify the type of height change or stated that there was none.

Rule 3 there was only one successful case with details of an airspeed change. There were 2 others with no such details.

Rule 4 there was one successful case with details of an airspeed change given. Two others without such details make up the total of 3.

Rule 5a there were 6 cases of which 3 reported details of airspeed changes but the other 3 did not. The maximum airspeed change (shared with Rule 5b) was 15 kn.

Rule 5b there were 87 cases of warnings successfully issued under Rule 5b by itself and another 20 in which it was in combination with one or more other rules. The maximum airspeed change was reported as 40 kn but the height was given only vaguely as 'less than 2,000 ft'. Otherwise the greatest airspeed change was 20-30 kn at 1500 ft and 20 kn at 500 ft and below. Below 500 ft there was one instance of a decrease in height being associated with an increase in airspeed. Otherwise, all increases in height were associated with increases in airspeed.

Rule 6a there were 4 cases of warnings successfully issued under Rule 6a by itself and a further 15 in combination with other rules. The maximum airspeed change was 32 kn at 400 ft. All changes greater than or equal to 20 kn below 750 ft are shared Rules 6a and 6c and it is not known to which, if either should be singled out, credit should be given. There were more Rules 6c than 6a but successes, nevertheless, in each.

Rule 6c As for Rule 6a. There were 15 cases of Rule 5c by itself and 18 shared cases.

Rule 7 there were only 2 cases with reported airspeed changes, both associated with decreases of height and both from Waddington aircraft.

4.5.2.4. From the graphs for Success Category 2 (Probably Successful) the following were noted:-

(i) there were 17 cases of Rule 5b being used to initiate a warning by itself. A further 7 were shared with other rules making a total of 24.

(ii) for Rule 6a there were 2 cases by itself and 6 shared with other rules making a total of 8

(iii) for Rule 6c there were 3 cases by itself and 4 shared with other rules making a total of 7

(iv) there was one case of Rule 2, 2 cases of Rule 3 and 1 case of Rule 7.

The largest airspeed change was 25 kn and arose from shear for which a warning was issued under Rule 6c. There was also a 20 kn airspeed change associated with a warning issued under Rule 6a. Altogether there were 54 'Probably Successful' cases. Of these, 26 Rules stand on their own, 22 were unsuitable for reasons such as that no airspeed change was given (18 cases) or that the airspeed fluctuated.

4.5.2.5. From the graphs for Success Category 3 (Probably Unsuccessful), the following were noted:-

(i) there were 41 probably unsuccessful cases. Of these 18 were in connection with warnings that were issued by themselves and the remaining 23 were in respect of reports that were unwritten (8), had no airspeed change reported (13) and had fluctuating airspeed changes (2).

(ii) the 18 warnings issued under single rules consisted of 9 under Rule 5b, 2 under Rule 6a, 1 under Rule 6c and 6 'others'.

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4.5.2.6. From the graphs for Success Category 4 (Unsuccessful) it was noted that:

(i) there were 161 unsuccessful cases. Of these, 23 were associated with warnings that had been originated from single rules and were made up from 6 under Rule 5b, 3 under Rule 6c, 5 under Rule 6a and 9 'others'.

(ii) a further 7 were shared between rules and some of the combined rules occurred several times.

(iii) altogether there were 45 instances consisting of 15 under Rule 5b, 7 under Rule 6c, 10 under Rule 6a and 12 'others'. These instances occurred either singly or in combination with other rules.

(iv) in 115 cases the warnings were unsuitable for plotting on the graphs. They were made up of 23 (unwritten reports), 14 (no airspeed change reported), 74 (no aircraft report received) and 4 cases of airspeed changes having consisted of fluctuations.

4.5.2.7. Graphs were also plotted showing the relationship between airspeed increases and decreases with height for all rules combined. It was noted that:

(i) in general, an increase in height was associated with an increase in airspeed and a decrease in height was associated with a decrease in airspeed. However, this was not always so. In the Success Category 1 graph, a decrease in height was associated with an increase in airspeed on 3 occasions at heights up to 100 ft. On the same graph there was one instance of an increase in height being associated with a decrease in airspeed. However there is reason to doubt this case.

4.5.2.8. Arising from such considerations as those above, alternative possible shear classifications suggested themselves as follows:-

(a)

Wind Shear Intensity	Airspeed Change (kn)		
Slight	0–10	or	0–5
Moderate	11–20	or	6–15
Severe	⩾ 21	or	⩾ 16

(b) Yet another possibility is

Slight	0–5 kn
Slight to Moderate	6–10
Moderate	11–20
Moderate to Severe	21–25
Severe	⩾ 26

These classifications are to be compared with that suggested in para 4.3.1.1.

4.5.2.9. One final note is that there was one case of + 32 kn and one of − 25 kn. Otherwise all airspeed changes were of 20 kn or less.

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4.6 Severity of Wind Shear in Relation to Aircraft Type

The main purpose of the trials was purely meteorological in that the intention was to try to find an effective means of giving timely warning of low level wind shear. The method of conducting them, however, involved the participation of 6 RAF stations in the winter Trial, 8 in the summer Trial and 3 civil airports in both Trials. Different types of aircraft were associated with the various stations as follows:-

4.6.1 Winter Trial

a. Civil Stations Trident (6 Marks), Viscount, HS 121, Tristar, L1011, VC9, Vanguard, VC8, V806X, V800, B707 and BAC 1-11.

b. RAF Stations Argosy, Belfast, Concorde Hercules VC 10, Buccanneer, Hunter, Canberra, Victor, Vulcan, Beaver, Devon & Nimrod. Out of 552 reports, 428 were from civil aircraft and 113 were from RAF aircraft. The following Tables show the numbers of reports from the different types of aircraft and the percentages of different intensities of shear that were experienced.

(i) Civil Aircraft

Aircraft Type	No of Reports	Percentage No of Reports of Shear Intensity					
		None	Slight	Mod	Severe	Oth.	All Shears
Trident 3	124	53	19	25	3	0	47
All Tridents	239	48.5	21	27	2.5	1	51.5
H/S aircraft	33	42.5	30.5	24	3	0	57.5
BAC 111	81	40.5	21	36	2.5	0	59.5
Viscounts	41	44	22	29	5	0	56
Other Civil a/c	34	59	17.5	14.5	9	0	41
All Civil a/c	428	47	21.5	28	3	0.5	53
(ii) RAF Aircraft							
Canberra	42	76	12	9.5	2.5	0	24
Victor	16	50	12.5	37.5	0	0	50
Buccaneer	14	78.5	0	21.5	0	0	21.5
Other RAF a/c	41	51	7.5	39	2.5	0	49
All RAF a/c	113	64	9	25	2	0	36
(iii) All Aircraft	541	50.5	19	27	3	0.5	49.5

4.6.1.1. It will be seen that on occasions when shear was forecast

(a) 47% of civil aircraft and 64% of RAF aircraft reported 'No Shear'.

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(b) 21.5% of civil aircraft and 9% of RAF aircraft reported 'Slight' shear.

(c) 28% of civil aircraft and 25% of RAF aircraft reported 'Moderate'=shear'

(d) 3% of civil aircraft and 2% of RAF aircraft reported 'Severe' shear.

4.6.1.2. It would appear that of about 70% of reports of 'no shear' or 'slight shear', pilots of civil aircraft were likely to be more aware of shear than pilots of RAF aircraft in the ratio of about 3:2 (64:47). Overall, civil aircraft would appear to be more susceptible to shear than RAF aircraft in the ratio of about 3:2 (53:36) and this is actually the case at the 'severe' level of intensity (3:2). However, the small number of cases involved must be borne in mind.

4.6.1.3. Reports of shear from both civil and RAF aircraft are more likely to be 'moderate' than 'slight'. The exceptions are civil HS aircraft which seem to be less susceptible to moderate shear and more susceptible to slight shear than other a/c (30.5:24). This also appears to be true but to a lesser extent for'other civil aircraft' - ie civil aircraft other than Tridents, BAC 111s and Viscounts (17.5: 14.5) but there would be some doubt over this because of the small number of reports (34).

4.6.1.4 On the RAF side aircraft reports of shear are also more likely to be 'moderate' than 'slight' - except Canberras which appear less susceptible to moderate shear. (12:9.5 for the slight to moderate ratio). There is a suggestion that Buccaneers do not experience slight shear because all reports from these aircraft were of moderate shear. This might be characteristic of a Buccaneer but it might also be due to the small number (14) of reports received. This latter seems much more likely but the former is interesting and cannot be ruled out.

4.6.2. Summer Trial

Different types of aircraft were associated with the various stations as follows:-

a. Civil Stations Trident (5 Marks), HS 21, HS 748, Viscount, VC 8, VC 9, VC 10, SVC 10, BAC 111 and S BAC 111, BAC H 1500, 747, DC 10, 707 and M'man.

b. RAF Stations HS 748, Andover, VC 10, Canberra. Navajo, Buccanneer, Nimrod, Canberra, Victor, Vulcan.

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Out of 162 reports, 65 were from civil aircraft and 97 from RAF aircraft. The following Tables show the numbers of reports from the different types of aircraft and the percentages of different intensities of shear that were experienced:-

(i) Civil Aircraft

Aircraft Type	No. of Reports	Percentage No of Reports of Shear Intensity					
		None	Slight	Mod	Severe	Oth	All Shears
All tridents	29	62.1	6.9	31.0	0	0	37.9
H/S Aircraft	2	100.0	0	0	0	0	0
Viscounts	6	83.3	16.7	0	0	0	16.7
747	7	42.9	28.6	14.3	0	14.3	57.2
707	5	40	20	40	0	0	60
Other Civil a/c	15	46.7	13.3	33.3	0	6.7	53.3
All Civil a/c	64	57.8	12.5	26.6	0	3.1	42.2

(ii) RAF Aircraft

Canberra	25	60	8.0	32.0	0	0	40
Victor	9	11.1	55.5	33.3	0	0	88.8
Vulcan	31	38.7	25.8	35.5	0	0	61.3
Bucanneer	6	100	0	0	0	0	0
Nimrod	19	21.1	63.1	15.8	0	0	78.9
Other RAF a/c	7	14.3	42.9	42.9	0	0	85.8
All RAF a/c	97	40.2	30.9	28.9	0	0	59.8
(iii) All A/C	161	47.2	23.6	27.9	0	1.2	52.7

It will be seen that on occasions when shear was forecast:-

(a) 57.8% of civil a/c and 40.2: of RAF aircraft reported 'No Shear'.

(b) 12.5% of civil a/c and 30.9% of RAF a/c reported 'slight' shear.

(c) 26.6% of civil a/c and 28.9% of RAF a/c reported 'moderate' shear.

(d) There were no reports of severe shear from any a/c, civil or RAF.

Comment

(i) It would appear that of about 70% of reports of no shear or slight shear, RAF aircraft made the pilots more aware of shear than civil aircraft in the ratio of about 3:2 (57.8 : 40.2). (In the winter trial the opposite was found to be the case, civil a/c appearing to be more susceptible - again in the ratio of 3:2). Overall, RAF a/c were more susceptible than civil a/c in the ratio of about 3:2 (59.8 : 42.2).

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This is the opposite to what was found in the winter trial when civil a/c were found to be the more susceptible - again in the same ratio of about 3:2).

(ii) Reports of shear from civil a/c appeared to be more 'moderate' than 'slight'. (26.6 to 12.5). Reports of slight and moderate from RAF a/c were about equally likely. (30.9 and 28.9). Viscounts appeared to be an exception on the civil side with 16.7% - but there was only 1 report. There were NO reports of slight or moderate shear from H/S aircraft so no comment can be made on the tentative conclusion from the winter trial that, against the general trend, they seemed to be less susceptible to moderate shear. For the summer trial, 'other civil a/c' appeared to be more susceptible to moderate shear which is in keeping with the general trend for civil a/c in both trials but opposite to that for 'other civil a/c' in the winter trial. However, there were only 15 reports for 'other civil a/c' in the summer trial.

On the RAF Side

(a) Overall, a/c were about as susceptible to moderate as to slight shear. Canberras appeared more susceptible to moderate shear but in the winter trial they were found to be less susceptible to moderate shear - so that tentative conclusion is nullified.

(b) Nimrods appeared to be more susceptible to slight shear in the ratio of about 4:1 (63.1 : 15.8). There was no comment on Nimrods for the winter trial.

(c) Vulcans were marginally more susceptible to moderate shear (35.5 : 25.8). There was no analysis in respect of Vulcans for the winter trial.

(d) There were no reports of shear from Buccaneers at all so nothing can be added to the comment that was made for the winter trial (i.e that Buccaneers do not experience slight shear.

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4.7 Changes in Ground Speed as an Indicator of Low Level Wind Shear

The very short term consequence to an aircraft in flight of a change in the wind vector is to produce a change in air speed. In the slightly longer term this would become manifest as a change in indicated ground speed but, since it occurs later, it is not as immediate an indicator of wind shear as the former. Although pilots were not asked specifically to comment on changes in ground speed on occasions when wind shear was encountered, a number did and the information they provided has been examined.

4.7.1 Winter Trial Although there would have been many more such changes that were not reported, there were 16 reports, all from London aircraft, of changes of ground speed arising from low level wind shear in the winter trial. Of these, 15 were in respect of aircraft that were landing and the other was from an aircraft that was taking off. In 11 of the 16, the reports related specifically to changes at heights below 1,000 ft but one of these was too vague to be of much use. In 8 of the remaining 10 the magnitude of the speed change was given and in 7 the height of the change was given. In 2 others a height range was given and in yet another a speed range was given, albeit in this last case with only a vague indication of the height at which it occurred.

Seven of the changes reported were of increases in ground speed while the remaining 3 were of decreases. A further report referred to a 'variation' implying both increase and decrease. The largest ground speed change reported was a decrease of 30 kn in a descent from 700 to 100 ft and of which the unspecified greater part occurred at 200ft. This was in association with a report of moderate shear. The largest change at any level was an increase of 24 kn, at 400 ft, again in association with what was reported as moderate shear. A small number of the reports of changes in ground speed were accompanied by references to drift but as this aspect will be dealt with in section (h) which follows, it will not be pursued here. One report included a reference to a power increase necessary to counteract an increase in rate of descent at 100 ft and in another a ground speed increase of 20 kn at 500 ft was attributed to a 40 kn headwind having rapidly reduced to 20 kn.

4.7.2 Summer Trial In the summer trial there was only one aircraft report containing a reference to ground speed. It was of an increase in ground speed in association with a decrease of 10 kn in airspeed. By itself, the report contributes nothing that would not already have been covered

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by the reports from the winter trial.

Suggestion

It is sugested that in a future trial, ground speed should be one of the parameters that pilots should be asked to log.

4.8 Comments on Drift in Association with Reports of Wind Shear

4.8.1 Winter Trial Comments specifically relating to drift were made in 22 of the 552 aircraft reports received. They were distributed between the participating stations as follows:-

	Lon	Glas	B'Ham	Tot Civ	BN	H'ton	Mar	Scam	W'ington	Wyt	St M	Kin
No. of a/c Rpts Received	325	54	50	429	22	15	34	3	8	41	-	-
No. with refs to drift	9	1	2	12	3	2	1	1	1	2	-	-

No. of a/c Rpts Rec'd Total RAF 123. Total Civ and RAF 552.

No. with refs to Drift -"- 10 -"- -"- 22

In only 7 of the 22 cases was a value for the change in drift given. The largest, of 15°, was accompanied by a wing drop and the pilot of the BAC 1-11 who encountered it when landing at his Birmaingham base deemed the shear to have been slight. He also reported an increase in MPPRM from 8600-8800 for about 5 seconds. In 8 cases, the drift was referred to by such adjectives as 'rapid', 'sudden onset','marked', and'unexpected'. One of these occurred when an RAF Hunter aircraft was landing at its Honington base. The pilot reported that the GCA centre line information he had been given by Air Traffic Control was good until a height of about 700ft. The aircraft then drifted rapidly left (into wind) and the GCA controller could not give heading changes quickly enough to prevent it finishing up 150 yards left of the centre line at the minimum descent height of 220 ft. ATC reported that other aircraft also had seemed to be drifting off the centre line at about the same range from touchdown.

Suggestion: Include drift on the Pilots Report Form of any future trial.

4.8.2 Summer Trial Comments specifically relating to drift were made in only 7 out of the 162 aircraft reports received. They were distributed between the participating stations as follows:-

	Lon	Glas	B'Ham	Tot Civ	BN	H'ton	Mar	Scam	W'ington	Wyt	STM	Kin
No. of a/c Rpts Received	53	10	2	65	5	9	26	22	9	10	0	16
No with refs to drifts	3	0	0	3	1	0	2	1	0	0	0	0

No. of a/c Rpts Rec'd Total RAF 97. Total Civ and RAF 162

No, with refs to drift. -"- 4 -"- -"- 7

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In only 3 of the 7 cases was a value for the change in drift given. The largest was a change from 11° to 0° and was associated with what was described as 'a rather severe directional change in wind velocity with no turbulence experienced' In one report the drift was said to be ' increasing rapidly' from its 7° starboard value at take-off.

In one case the drift was reported to have changed from 8R to 4R and the headwind velocity changed from 25 to 10 kn while the aircraft descended from 1500 to 400 ft where moderate shear was experienced. In another case of moderate shear mild turbulence was reported and there was an unspecified variation in drift. Another unspecified change of drift was associated with slight shear at 200ft. In a report of moderate shear between 200 and 800 ft the starboard drift increased during the final approach, the headwind component decreased and the a/c went above the glidepath. There was also one report in which reference was made to drift becoming fairly constant on becoming airborne but no shear was experienced.

4.9 Reports of Turbulence in Association with Wind Shear

Turbulence and wind shear frequently occur together and pilots can mistake one for the other. Turbulence can occur by itself but the nature of wind shear is such that it would not occur without some measure of turbulence. On occasion the amount of turbulence experienced was reported to have been such as to have masked effects such as fluctuations in airspeed and rate of climb which may have been due to wind shear. Notwithstanding this, the extent to which turbulence was reported during the Trials was investigated by relating its severity to that of shear for all aircraft reports received from the different stations. The results are given in the Tables below:-

4.9.1 Winter Trial

	Intensity of Shear	No Turbulence Reported	Severity of Turbulence Slight	Moderate	Severe	Unspecified	Total
(a) RAF Stns	Slight	8	3	1	0	2	14
	Moderate	14	5 1	3	1	5	29
	Severe	0	0	1	0	0	1
	Total	22	8 1	5	1	7	44
	No shear	73	1	4	0	1	79
	Grand Total	95	9 1	9	1	8	123
(b) Civ Stns	Slight	63	22 2	3	0	4	94
	Moderate	70	16 8	12	0	13*	119
	Severe	6	2	4	1 0	2*	15
	Total	139	40 10	19	1 0	19	228
	No shear	182	14 1	2	0	2	201
	Grand Total	321	54 11	21	1 0	21	429

* Includes 1 'other reply'

(c) ALL Stns	Slight	71	27 2	4	0	6	108
	Moderate	84	21 9	15	1	18*	148
	Severe	6	2	5	1 0	2*	16
	Total	161	48 11	24	1 1	26**	272
	No shear	255	15 1	6	0	3	280
	Grand Total	416	63 12	30	1 1	29	552

* Includes 1 'other reply'; ** includes 2 'other replies'

It will be seen from these tables that

(i) No turbulence was reported on 416 of the 552 reports received. The absence of any mention of turbulence does not necessarily mean that there was none but it is likely that, in the main, this was probably the case.

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(ii) There were 272 Reports of 'positive shear'. Of these

(a) For 161 there was no turbulence reported

(b) For 24 there was turbulence of an unspecified severity - probably no more than slight

(c) For 46 there was slight turbulence

(d) For 11 there was slight to moderate turbulence

(e) For 24 there was moderate turbulence

(f) For 1 there was moderate to severe turbulence

(g) For 1 there was severe turbulence

and there was one other reply

(iii) There were cases of moderate turbulence with slight shear but no cases of severe turbulence with slight shear

(iv) There was only one case of 'severe turbulence' and it was associated with moderate shear. One case of moderate to severe turbulence was associated with 'severe' shear.

(v) There were 255 cases of 'no shear'. Of these there were

(a) 15 reports of slight turbulence

(b) 1 report of slight to moderate turbulence

(c) 6 reports of moderate turbulence

but there were no cases of severe turbulence. This would not be unexpected.

4.9.2 Summer Trial

a.

	Intensity of Shear	Severity of Turbulence: None Reported	Slight	Moderate	Severe	Unspecified	Total
Civ Stns	Slight	5	2	1	0	0	8
	Moderate	12	3	2	0	1	18
	Severe	0	0	0	0	0	0
	Totals	17	5	3	0	1	26
	No shear	33	4			1	38
	Totals (All Reports)	50	9	3		2	64

b.

	Intensity of Shear	Severity of Turbulence: None Reported	Slight	Moderate	Severe	Unspecified	Total
RAF Stns	Slight	23	4	2	0	1	30
	Moderate	24	1	0	0	3	28
	Severe	0	0	0	0	0	0
	Totals	47	5	2	0	4	58
	No shear	36	0	1	2	0	39
	Totals (All Reports)	83	5	3	2	4	97

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		Severity of Turbulence				
	Intensity of Shear	None Reported	Slight	Moderate	Severe	Unspecified	Total
c. All Stns	Slight	28	6	3	0	1	38
	Moderate	36	4	2	0	4	46
	Severe	0	0	0	0	0	0
	Totals	64	10	5	0	5	84
	No shear	69	4	1	2	1	77
	Totals (All Reports)	133	13	6	2	6	161

It will be seen from these Tables that:-

(i) No turbulence was reported on 133 of the 161 reports received. The absence of any mention of turbulence does not necessarily mean that there was none but it is likely that, in the main, this was probably the case.

(ii) There were 84 reports of positive shear. Of these

(a) For 64 there was no turbulence reported

(b) For 10 there was slight turbulence

(c) For 5 there was moderate turbulence

(d) There were no cases of severe turbulence - or, indeed, severe shear.

(e) For 5 cases there was turbulence of an unspecified severity.

(iii) There were 69 cases of 'NO shear'. Of these, there were

(a) 4 reports of slight turbulence

(b) 1 report of moderate turbulence

(c) 2 reports of severe turbulence

(d) 1 report of unspecified turbulence

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4.10 The Possibility of Wind Shear arising from the proximity of such as Aircraft Hangars

It has been suggested that low level wind shear could, in certain meteorological situations, arise from or be enhanced by the proximity of large buildings such as aircraft hangars and the large number of pilots' reports available from these Trials provided an opportunity to look into this, albeit limited because no specific requests to pilots for such information had been made. Nevertheless, the possibility existed that relevant useful information might be included on some of the reports and that if it did not lead to anything conclusive it might indicate the lines along which a further investigation could usefully proceed.

4.10.1 From the Winter Trial there were 11 reports (out of the 552) in which reference was made to hangars and of these, 9 were from London, 1 was from Birmingham and one was from RAF Wyton. Of the 9, 8 were in respect of aircraft that had been landing and the other was from the pilot of an aircraft that had been taking off. Of the 11 reports, 8 were associated with shear while for the other 3 there was no shear. In 7 out of the 8 the shear was reported as of moderate intensity while in the other case it was slight. Furthermore, for 6 of the 7 London cases, wind directions lay between 190 and 220 degs and wind speeds were between 12 and 19 kn. In the 7th case the wind was on the reciprocal direction of 040 degs and the speed was 20 kn. For 7 of the 8 cases of positive shear the associated change in airspeed was reported. In 3 cases the airspeed increased by between 10 and 20 kn in 2 cases it decreased by 10 and 12 kn and in the other 2 cases it both increased and decreased by up to 10 kn.

In each of the 3 cases when no shear was reported a comment was made to the effect that normal turbulence was experienced in the area of the hangars. This included the one report from the Birmingham aircraft. On this occasion the wind was 270-280 degs 21-24 kn. In the case of the Wyton report the comment was made that the shear was associated with turbulent flow over the hangar - a fairly common experience on Runway 09 when the wind is SE'ly.

The tentative conclusion to be drawn from this brief and superficial investigation is that Heathrow is, indeed, an aerodrome where low level wind shear can arise due to the proximity of a hangar. When this happens, the surface wind is usually SSW'ly in direction and with a speed in excess of 12 kn. However it can also happen with a roughly reciprocal wind direction but less frequently, possibly

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partly because a higher wind speed (of about 20 kn) is required to initiate it. Shear arising from such circumstances can manifest itself as either an increase or decrease in indicated airspeed or both. The height of occurence is 300 ft or below. It also appears that RAF Wyton has a similar problem with a SE'ly wind when Runway 09 is in use. On occasion, however, these same surface wind speeds and directions produce only turbulence without shear and it might be worthwhile looking further into this.

With the reservation that aircraft reports from other airfields taking part in the Trials were considerably fewer than those from London, there were, apart from the one from RAF Wyton, no reports or suggestions of shear arising from such as their aircraft hangars. In the absence of any other evidence it would seem that the hangars at these other stations are not so constructed or so positioned as to be conducive to the initiation of shear.

4.10.2 From the Summer Trial there were only 2 references to the effects of buildings. The first of these, on 28.7.77 from the pilot of an LAP aircraft, was in association with a report of turbulence but no shear. The second, from a Brize Norton aircraft on 5 Jul 77 was in association with a report of slight shear experienced at a height of 100-150 ft and without being specific would clearly seem to have been referring to a building when making the comment:-

'Slight wind shear of this nature has often been experienced by me at this position with an easterly wind'.

With such sparse information, the summer trial has contributed little of value to this particular investigation.

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4.11 Aircraft Handling Difficulties arising from wind shear

Included among the questions on the forms used by the pilots to report wind shear were several relating to aircraft handling difficulties that arose and the measures taken by the pilot to deal with them. They were:-

a. Did you experience any handling difficulty?

b. Was autopilot engaged?

c. Was autothrottle engaged?

d. Did you disengage autopilot?

e. Did you disengage autothrottle?

Answers to these questions were to be 'Yes' or 'No' but there were cases where such answers were not applicable and others where for no obvious reason, no reply was given. Where answers were given, however, they were analysed for different aircraft and intensities of shear.

The most important question concerned whether or not any handling difficulty was experienced and the answers to this are analysed in the following tables for cases of slight, moderate, severe and all intensities of shear:-

4.11.1 Winter Trial

Aircraft Handling Difficulty Experienced

a. RAF a/c	Yes: Shear Intensity Slight	Mod	Sev	Totals No	out of	%	No: Shear Intensity Slight	Mod	Sev	Totals No	out of	%
Argosy	0	0	0	0	4	0	1	3	0	4	4	100
Buccanneer	0	0	0	0	3	0	0	3	0	3	3	100
Canberra	0	0	0	0	9	0	5	4	0	9	9	100
VC 10	0	0	0	0	3	0	0	2	0	2	3	66.7
Vulcan	0	4	0	4	10	40	3	3	0	6	10	60
Victor	1	2	1	4	10	40	2	4	0	6	10	60
Devon	0	0	0	0	1	0	0	1	0	1	1	100
Hunter	0	0	0	0	1	0	0	1	0	1	1	100
Nimrod	0	2	0	2	4	50	1	1	0	2	5	40
Totals	1	8	1	10	45	22.2	12	22	0	34	46	73.9
b. Civ a/c												
Trident	0	7	2	9	142	6.3	62	63	4	129	142	90.8
Viscount	0	3	1	4	25	16	11	9	1	21	25	84
Tristar (L1011)	0	1	0	1	5	20	2	1	1	4	5	80
BAC 111	1	1	1	3	47	6.4	15	28	1	44	47	93.6
Vanguard	0	0	0	0	5	0	0	3	2	5	5	100
B707	0	0	0	0	2	0	2	0	0	2	2	100
	1	12	4	17	226	7.5	92	104	9	205	226	90.7
Totals all a/c	2	20	5	27	272	9.9	104	126	9	239	272	87.9

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Comments (i) RAF a/c It will be seen that 3 of the 9 types of aircraft that encountered shear that was successfully forecast, experienced handling difficulty. These were the Vulcan (40% of 10), Victor (40% of 10) and Nimrod (40% of 5). It would seem therefore, that despite the small numbers of flights involved, 40% would be a reasonable figure for the numbers of Victors, Vulcans and Nimrods that could expect to present handling difficulty when encountering wind shear.

A more complete look into this would require the breakdown into slight, moderate and severe shear and the following figures are taken from the table above:

Shear Intensity	Handling Difficulty – Answer is Yes					
	Vulcan	out of	Victor	out of	Nimrod	out of
Slight	0	3	1	3	0	1
Moderate	4	7	2	6	2	3
Severe	0	0	1	1	0	0
Totals	4	10	4	10	2	4
Percentage	40		40		50	

The only aircraft that presented handling difficulty with severe shear was the Victor. It was also the only one that presented handling difficulty with slight shear. With moderate shear, all 3 aircraft experienced handling difficulty with little to choose between the Vulcans (4 out of 7) and Nimrods (2 out of 3) but the Victors seemingly rather better with 2 out of 6. However, any such conclusions in respect of the Victors must be seen against its having exhibited handling difficulty at all 3 shear intensities.

(ii) Civil Aircraft

It is seen from the lower half of the Table on page 40 that:

(a)	6.3%	of	142	Trident	Reports of shear
(b)	16%	of	25	Viscount	" " "
(c)	20%	of	5	Tristar	" " "
(d)	6.4%	of	47	BAC 111	" " "
(e)	0.0%	of	5	Vanguard	" " "
(f)	0%	of	2	B707	" " "

} Reported handling difficulty

This could suggest that handling difficulties arising from wind shear increase in the following order of aircraft:- B707 & Vanguard, Trident, BAC 111, Viscount, Tristar. The small number of cases of Vanguard (5) and the B707 (2) makes such a conclusion in respect of these 2 aircraft unreliable. But since there were also only 5 Tristar cases it suggests that Vanguards present less handling difficulties than Tristars. It might be thought that Tristars with 20% present marginally greater difficulties than

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Viscounts with 16% but with only 5 Tristar reports the number is too small for a firm conclusion. What does seem more definite is that BAC 111s and Tridents present less handling difficulties in shear conditions than Viscounts (almost certainly) and Tristars (probably).

A more complete look into this would require the breakdown into slight, moderate and severe intensities of shear and the following figures have been taken from the above Table for that purpose.

Shear Intensity	Handling Difficulty – Answer is 'Yes'											
	Viscount		Tristar		BAC 111		Vanguard		B707		Trident	
		out of		out of		out of		out of		out of		out of
Slight	0	11	0	2	1	16	0	0	0	2	0	62
Moderate	3	12	1	2	1	29	0	3	0	0	7	70
Severe	1	2	0	1	1	2	0	2	0	0	2	6
	4	25	1	5	3	47	0	5	0	2	9	138

Here there seems to be nothing to choose between Viscounts and BAC 111s in the handling difficulties presented by severe shear (1 out of 2 for each aircraft) but with only 2 out of 6, Tridents are better. With 1 out of 29 for BAC 111s and 3 out of 12 for Viscounts for handling difficulties in moderate shear, the BAC 111s seem to be the better, even better than Tridents with 7 out of 70. For slight shear it is difficult to draw a firm conclusion with 0 out of 11 for Viscounts and 1 out of 16 for BAC 111s but, if anything, the Viscounts are slightly better. With 0 out of 62, Tridents are better still.

The following Table summarises the answers to the questions for all aircraft and all intensities of shear and allow of a general comparison between RAF and Civil aircraft from, respectively, the 46 and 226 pilot report forms received.

(a)		Answers	Handling Difficulty		Autopilot Engaged		Autothrot Engaged		AutoPil Diseng		Autothrot Diseng	
	RAF a/c	Yes	10	21.7%	0	0%	0	0%	0	0%	0	0%
		No	34	73.9%	44	95.7%	40	87%	21	45.7%	16	34.8%
		No reply	2	4.3%	2	4.3%	4	8.7%	20	43.5%	24	52.2%
		N/A	0	0%	0	0%	2	4.3%	5	10.9%	6	13.0%
			46	99.9%	46	100%	46	100%	46	100.1%	46	100.0%
	Civ a/c	Yes	17	7.5%	33	14.6%	73	32.3%	36	15.9%	29	12.8%
		No	205	90.7%	193	85.4%	126	55.7%	100	44.2%	118	52.2%
		No reply	2	0.9%	0	0.0%	18	8.0%	65	28.8%	55	24.3%
		N/A	0	0.0%	0	0.0%	9	4.0%	25	11.1%	24	10.6%
		Other ans	2	0.9%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
			226	100%	226	100%	226	100%	226	100%	226	99.9%

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4.11.2 Summer Trial

Aircraft Handling Difficulties Experienced

	Yes						No					
a. RAF a/c	Shear Intensity			Totals			Shear Intensity			Totals		
	Slight	Mod	Sev	No	out of	%	Slight	Mod	Sev	No	out of	%
Canberra	0	1	0	1	10	10	2	7	0	9	10	90
Victor	0	0	0	0	8	0	5	3	0	8	8	100
Vulcan	3	4	0	7	19	36.8	5	6	0	11	19	57.9
Buccaneer	0	0	0	0	0	0	0	0	0	0	0	0
Nimrod	0	1	0	1	15	6.7	12	2	0	14	15	93.3
Other RAF a/c	0	0	0	0	6	0	1	3	0	4	6	66.7
	3	6	0	9	58	15.5	25	21	0	46	58	79.3
b. Civ a/c												
Trident	0	0	0	0	11	0	1	9	0	10	11	90.9
111 & S111	0	0	0	0	1	0	0	1	0	1	1	100
Viscount	0	0	0	0	1	0	1	0	0	1	1	100
747	0	0	0	0	3	0	2	1	0	3	3	100
707	0	1	0	1	3	33.3	1	1	0	2	3	66.7
Other Civ a/c	0	1	0	1	7	14.3	2	4	0	6	7	85.7
	0	2	0	2	26	7.7	7	16	0	23	26	88.5

Comments (i) RAF Aircraft Three of the RAF aircraft that encountered shear that was successfully forecast experienced handling difficulty. These were the Canberra (10% of 10), Vulcan (36.8% of 19) and the Nimrod (6.7% of 15). It would seem, therefore, that despite the small numbers of flights involved, the Vulcan is the more susceptible of the RAF aircraft to experiencing handling difficulty when encountering shear and, with 10% and 6.7%, little to choose between Canberras and Nimrods. These figures are to be compared with those for the winter trial in which Vulcans and Nimrods were again two of the three types of RAF aircraft experiencing handling difficulty. The value for the Vulcan from the winter trial was 40% which compares with the summer value of 36.8%. However, the value for the Nimrod of 40% of 10 flights from the winter trial is appreciably greater than that of 6.7% of 15 flights from the summer trial. With the larger no. of 15 flights from the summer trial, greater weight should be attached to the figure of 6.7%. Victor aircraft presented no handling difficulties from 8 flights in the summer trial and Canberras presented no handling difficulties from 9 flights in the winter trial.

The conclusion in respect of RAF aircraft is therefore, that in conditions of low level shear, handling difficulties are more likely to be experienced by Vulcan aircraft, less likely by Nimrods, even less likely by Victors and less likely still from Canberras.

A breakdown by shear intensity of the 7 out of 19 cases for Vulcans from the summer trial is as follows:-

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Shear Intensity	Vulcan Aircraft No	Out of
Slight	3	8
Moderate	4	11
Severe	0	0
Total	7	19

The single Canberra case and the single Nimrod case were both in association with moderate shear.

(ii) Civil Aircraft In only 2 out of 26 cases from the summer trial was handling difficulty experienced by civil aircraft. One of these was by a6707 in moderate shear and the other was among 'other civil aircraft', also in moderate shear. It is significant that from 11 cases, there were no reports of Tridents having experienced handling difficulty and this is in line with the indication from the winter trial (only 6.3% of 142 cases).

Conclusion With only 2 out of 26 cases (7.7%) for civil aircraft compared with 9 out of 58 cases (15.5%) from RAF aircraft, the inference from the summer trial is that civil aircraft are less susceptible to shear than RAF aircraft. This is in line with the findings from the winter trial from which the corresponding figures were 7.5% of 226 cases for civil aircraft and 21.7% of 46 cases for RAF aircraft. Because of the greater number of cases, greater weight would be attached to the results from the winter trial but those from the summer trial, nevertheless support them.

The following table summarises the answers to the questions for all aircraft and all intensities of shear and allow of a general comparison between RAF and Civil aircraft.

(a)

RAF a/c Answers	Handling Difficulties		Autopilot Engaged		Autothrot Engaged		AutoPil Diseng		Autothro Diseng	
Yes	9	15.5%	0	0%	0	0%	0	0%	0	0%
No	46	79.3%	51	87.9%	31	53.4%	13	22.4%	10	17.2
No reply	3	5.2%	7	12.1%	25	43.1%	42.1	72.4%	47	81.0
N/A	0	0%	0	0%	2	3.4%	3	5.2%	1	1.7
	58	100%	58	100%	58	99.9%	58	100%	58	99.9
Civ a/c										
Yes	2	7.7%	8	30.8%	7	26.9%	1	3.8%	3	11.5
No	23	88.5%	17	65.4%	16	61.5%	14	53.8%	11	42.3
No reply	1	3.8%	1	3.85%	3	11.5%	10	38.5%	11	42.3
N/A	0	0.0%	0	0.0%	0	0	1	3.8%	1	3.9
	26	100%	26	100%	26	99.9%	26	99.9%	26	100%

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4.12 Additional Comments by Pilots

4.12.1 Winter Trial Without being specific pilots were asked to make in their reports any comments which they considered relevant to the wind shear they were experiencing. Those concerned with ground speed, drift, turbulence, proximity of hangars and aircraft handling difficulties have been examined in sections 4.7 to 4.11above. In this section attention is focussed on the many other comments that were made.

The value of a report of wind shear experienced by one aircraft being communicated to another was amply brought out. In one case the pilot was ready to deal with an approach tailwind that became a headwind on finals. There were also cases where the pilot commented on the positive value of the forecast of wind shear he had received - again, in enabling him to be prepared for any necessary action. Such action usually concerned a decision on whether or not to change from auto to manual control of the aircraft.

Updraughts, downdraughts and both were included in the reports. In association with one report of severe wind shear at Heathrow, severe updraughts and downdraughts with the rider 'as is known on Runway 23' were reported. In one report of moderate shear an associated strong updraugh caused the aircraft to gain 200ft but the approximately 1,000ft height at which it happened would not have been such as to have constituted danger. In another case where both were reported, the strong updraught which followed the strong downdraught occurred in the last 100ft and it is apparent how much more dangerous it would have been if their order had been reversed.

The effect of wind shear was made manifest by such as the following:-

a. wing drop in one case it was reported as having occurred at a height of 10ft and in another it was described as 'violent' and accompanied by a 'wallowing (of the aircraft) for about 5 seconds'.

b. wing lift

c. landed too fast

d. landed too slow

e. change in heading - reported as 'marked' during a PAR talkdown' by one pilot.

f. an increase or decrease in the rate of descent (for landing) or climb (for take-off).

g. momentary stick shake

h. involuntary yawing - in one case reported as $\pm 3^{o}$.

j. yaw dampers came out

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k. wave-like rolling motion

l. continuous roll effects "& rolling movement"

m. gaining and/or losing airspeed. In one case 10kn gained at 1200ft was followed by 15kn lost at 100ft and in another a gain of 11kn at 700ft was followed by a loss of 10kn at 100ft. In yet another it was reported that the most severe wind shear experienced and with the greatest rate of speed loss was at 100ft or below and it is in changes such as these that the real danger lies. Fluctuations of a few kn in airspeed were thought to have been mainly due to turbulence.

n. auto-throttle reaction - though not all participating aircraft were fitted with autothrottles. Autothrottle change could mask the change in IAS.

p. the main effect of wind shear arising primarily from loss or gain or fluctuations of height and/or airspeed and to which those given above are subsidiary or contributing factors is to create difficulty in maintaining the aircraft on the glidepath. In some cases it became necessary to overshoot.

q. in more human terms the effects of wind shear were described by various pilots as having made the flight 'rough', or having given rise to 'that sinking feeling' or plain 'fright' !

To alleviate the effects of wind shear pilots often found it necessary to assume manual (as opposed to auto) control of the aircraft and to alter power settings. One pilot reported that he contained the increased speed he experienced as a result of shear by raising the nose of the aircraft thereby increasing the rate of climb to 2,000ft/min. A simple precautionary measure often adopted by pilots in the light of a forecast of wind shear is to fly the aeroplane faster than normal and one pilot reported having increased his approach speed by 10kt for this reason.

4.12.2 Summer Trial Many of the comments made by pilots in the Summer Trial were already included in the Winter Trial. The following were considered to be worth adding:-

a. One necessary power setting change was described as 'considerable' and another increase described as 'large'.

b. One a/c experienced no shear after ATC had passed a report from another a/c a few mins earlier. This is indicative of the variability and non-persistent nature of shear.

c. Change in ground speed.

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d. a/c high or low on the glidepath

e. Difference of opinion as to whether something experienced was shear or not. On one occasion the Flying Instructor thought that what was being experienced was turbulence but the student disagreed and thought it was shear.

f. A low level inversion in the last 100ft was apparent from the behavious of smoke in very calm conditions.

g. No loss of height or gain of speed but as a/c descended, wind changes were apparent in the 800-400 ft AGL band.

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5. Summary of the Findings

The following is a summary of the findings from the low level evidence that became available from the trials:-

A. Meteorological

1. (a) The Summer Trial versions of Rules 3, 4, 5a, 5b, 6a and 6c were sufficiently successful as to merit their qualified use in an operational Shear Warning system.

(b) Rules 1, 2 and 6b were either unsuccessful or sufficiently so as to merit excluding them from any operational warning system.

2. From a consideration of the reported cases of 'Severe' shear:

(a) half of those from the winter trial were in the height band 200-600 ft which, therefore, even if it be not the most important, must be considered to have some special significance.

(b) the proximity and central values of pressure systems did not show any correlation with the occurrence of shear.

(c) a cold front or trough was found to be more likely to give rise to shear than a warm front.

(d) there was a greater probability of shear in winter with surface wind directions between 135 and 270 degs and gradient wind directions between 135 and 315 degs.

(e) there was no evidence of summer shear being associated with any particular range of wind directions.

3. Reported Cases of Shear of any Intensity when no Warning had been issued

From a consideration of

(a) Radio-sonde Ascents

(i) shears derived from winds at 10m and that at the next lowest reported level of a radio-sonde ascent had values up to 3 kn/100 ft in winter and 2 kn/100 ft in summer

and (ii) corresponding temperature lapse rates were up to 3°/100 ft in winter and 2.25/100 ft in summer

but (iii) radio-sonde ascents are unlikely to provide information of use in forecasting the occurrence of low level wind shear.

(b) The Speeds of Surface (ff) and Gradient Winds ($f_G f_G$) and Surface Gusts ($f_g f_g$)

(i) no shear whatsoever was reported for $f_g f_g$ less than 14 kn and ff less than 8 kn

(ii) lower limit for reports of 'severe' shear were 13 kn for ff with $f_g f_g \geqslant 16$ kn

and 35 kn for $f_G f_G$ with $f_g f_g \geqslant 15$ kn

4. No obvious association was found between shear and subjective reports of turbulence. No turbulence was reported in 161 out of 272 reports of positive shear from the winter trial and from 133 out of 161 from the summer trial.

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B. Local

5. Shear arising from Buildings

Available evidence suggests the liklihood that:

(a) with a surface wind speed ≥ 12 kn from a SSW'ly or roughly reciprocal direction, shear at heights below 300 ft can arise at London (Heathrow) Airport from the effects of aircraft hangars.

(b) an aircraft hangar at RAF Wyton can also give rise to shear on Runway 09 with a SE'ly surface wind.

(c) a building at RAF Brize Norton is conducive to the incidence of slight shear at heights below 150 ft in an easterly wind.

(Note It is not necessarily the case, however, that the absence of such reports from other stations would be the result of hangars or other buildings not being so constructed or positioned as to be conducive to the initiation of shear.)

C. Aeronautical

6. In general, shear conditions resulted in an increase in aircraft height being associated with an increase in airspeed and vice-versa. There were, however, 3 cases of shear having been successfully forecast when the opposite was the case.

7. Aircraft Type

(a) From the Winter Trial

(i) Civil aircraft were found to be more susceptible to shear than RAF aircraft in the ratio 3:2.

(ii) there were significantly more reports of moderate than slight shear from both Civil and RAF aircraft.

(iii) there was evidence, albeit from only 14 reports received, that Buccanneers, moreso than other RAF aircraft, are not noticeably affected by slight shear.

(b) From the Summer Trial

(i) RAF aircraft were found to be more susceptible to shear than Civil aircraft. (This is opposite to the findings from the Winter Trial)

(ii) Civil aircraft were found to be more susceptible to moderate than slight shear.

(iii) RAF aircraft were found to be about equally susceptible to moderate and slight shear.

8. Aircraft Handling Difficulties arising from Shear

(a) RAF Aircraft

(i) Of 9 types of RAF aircraft, handling difficulties in shear conditions were experienced moreso in Vulcans, Nimrods, Victors and Canberras.

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(b) Civil Aircraft

(i) Handling difficulties in the Winter Trial were experienced in B707s, Vanguards, BAC 111s, Tridents, Viscounts and Tristars in that increasing order.

(ii) BAC 111s and Tridents presented less handling difficulties than Viscounts (almost certainly) and Tristars (probably).

(iii) the lower susceptibility of Tridents referred to in (ii) above was borne out from the Summer Trial, in none of 11 reports from which was any handling difficulty reported.

(iv) from both Trials but with greater weight being attached to that in the Winter because of the greater number of cases, Civil aircraft were found to be less susceptible to handling difficulties arising from wind shear.

9. Of particular interest in that they present a human as opposed to a purely scientific approach to the problems of wind shear are the comments which, since they are given in para 4.12 above, will not be repeated here.

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6. Recommendations

It is recommended that:

1. An operational low level wind shear warning system be introduced for use within the UK based on any of the following criteria being satisfied:-

   (i) $|V_G - V_{10}| \geqslant 40$ kn

   (ii) A cumulonimbus cloud within 5 km or a thunderstorm within 10 km is approaching the station (See note below)

   (iii) There is within 50 nm of the station an active front moving at a speed of 30 kt and/or having a wind change across it of at least 10 kt (See note below)

   Note

   Inasmuch as an overhead cumulonimbus with tops of 30,000 ft is likely to have more potential for and a greater imminence of shear than one 5 km away with tops of 20,000 ft, there is a case for assigning a probability to these warnings. Another reason for doing so is that a cold front or trough is more likely to give rise to shear than a warm front.

2. Insofar as is possible, special attention should be paid to the height band 200 - 600 ft when considering issuing warnings.

3. In any future Low Level Wind Shear Trial, similar to those held in 1977, pilots should be asked specifically to report on

   (i) the magnitude of groundspeed changes

   (ii) the magnitude of drift

   (iii) turbulence

4. The following alternative classifications of wind shear in relation to consequential airspeed changes be considered for adoption:-

(a)
   (i) Slight - airspeed change of less than 10 kn

   (ii) Moderate - airspeed change of 10-19 kn

   (iii) Severe - airspeed change of 20 kn or more.

(b)
   (i) Slight - 0-5 kn airspeed change

   (ii) Slight to Moderate 6-10 kn " "

   (iii) Moderate 11-20 kn " "

   (iv) Moderate to Severe 21-25 kn " "

   (v) Severe $\geqslant$ 26 kn " "

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7. References

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3. Sowa D 1974 Low Level Wind Shear DC Flight Approach No 20 pp 10-15
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8. Acknowledgements

Acknowledgements are due to

(i) the meteorological staffs at the Civil airports and RAF stations who filled in the observation forms and issued the wind shear warnings over a total period of six months

and (ii) the British Airways and RAF aircrews who provided the reports of wind shear.

The author is particularly grateful to Mrs J. Francis of the Meteorological Office Bracknell, who assisted in the analysis of the data.

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APPENDIX A

RULES FOR ISSUING WARNINGS OF LOW LEVEL WIND SHEAR (WINTER TRIAL JANUARY TO APRIL 1977)

NOTATION:

$\underline{V}_{10}$ = Surface (10 metre) wind (vector)

$V_{10} = |\underline{V}_{10}|$ = Surface wind speed (scalar)

$\underline{V}_G$ = Gradient (600m, 2,000 ft) wind (vector)

$V_G = |\underline{V}_G|$ = Gradient Wind speed (scalar)

RULES

If (1) $V_{10} \geqslant$ 30 kn

(2) $V_{10} \geqslant$ 10 kn and $V_G - 2V_{10} \geqslant$ 25 kn

(3) $V_{10} <$ 10 kn and $|\underline{V}_G - \underline{V}_{10}| \geqslant$ 40 kn

(4) $V_{10} <$ 10 kn and $|\underline{V}_G - \underline{V}_{10}| \geqslant$ 30 kn and an inversion or isothermal layer is present below 600m (2,000 ft)

(5) (a) a thunderstorm within 20 km

or

(b) a cumulonimbus cloud within 10 km

of the approach/climbout has been observed

(6) from a front within 50 nm of the station, there is on the approach/climbout a frontal surface

(a) with a vector wind change across it of at least 10 kn magnitude - noted either locally or at a neighbouring station from the passage of the front)

or (b) having a temperature difference across it of at least 5 degs C

or (c) moving at a speed of at least 30 kn

(7) a significant low level jet is suspected at or below 600m

(8) a report of low level wind shear has been received

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APPENDIX B LOW LEVEL WIND SHEAR WARNING TRIAL - JANUARY TO APRIL 1977
VARIABLES LOGGED HOURLY ON 'OBSERVATION AND WARNING FORM'
(adapted, as shown in Appendix C, from a FORTRAN Coding Form)

Column Numbers	Code Letters	Description
1 - 3	iii	Station number
6 - 11	MMDDGG	Month : Day : Time (GMT)
14 - 17	ddff	Most recent H + 50 Surface wind (10 minute mean: tens of degrees : whole knots)
20 - 21	$f_g f_g$	speed of maximum gust in the last 10 minutes (whole knots)
24 - 26	$\pm T_a T_a$	Surface dry bulb temperature (whole degs C)
28 - 31	$d_G d_G f_G f_G$	Gradient wind (tens of degrees : whole knots) at time of observation. Filled in in retrospect after the hourly chart became available.
34 - 35	$f_a f_a$	$(V_G - 2V_{10})$ (i.e. $f_G f_G - 2ff$: whole knots). Filled in only if $V_{10} < 10$ kn.
38 - 41	$d_b d_b f_b f_b$	$(V_G - V_{10})$ (tens of degrees: whole knots). Filled in only if $V_{10} < 10$ kn.
44	I	Inversion/isothermal considered to be present below 600m. (No = ø : Yes = 1)
47	T	Thunder heard during past hour (No = ø : Yes = 1)
50	C	Cumulonimbus within 10km (No = ø: Yes = 1)
53	S	Type of front. 0 = no front: 1 = Warm: 2 = Cold: 3 = Occlusion: 4 = Quasistationary:
54 - 55	$f_c f_c$	Observed magnitude of 10 metre wind speed change across the front (whole knots). (99 if no front)
58 - 59	$f_s f_s$	Speed of front (whole knots). (99 if no front)
63 - 64	$T_c T_c$	Surface temperature change across the front (whole degs C) as measured at any appropriate station in one hour (99 if no front)
66	J	Low Level Jet. (No = ø : Yes = 1)
69	W*	Low Level Wind Shear Warning issued.

*Code for W

ø = no warning issued: no aircraft report received
1 = no warning issued: aircraft report received (an explanation of why would normally be necessary)
2 = warning issued : aircraft report received
3 = warning issued : one of the criteria 1 - 4 satisfied.
4 = warning issued : thunderstorm or cumulonimbus in vicinity
5 = warning issued : Low Level Jet suspected
6 = frontal surface on glide slope

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FORTRAN Coding Form

PROGRAM LOW LEVEL WIND SHEAR WARNING TRIAL | PUNCHING INSTRUCTIONS | GRAPHIC / PUNCH | PAGE

PROGRAMMER | DATE DD/MM

STATEMENT NUMBER | CONTINUATION | FORMAT STATEMENT I

M MDDGG ddff fsfs ±TaTa ddff fsfs dbdbfbfb T C Sfcfcfc

COMPLETED FORMS SHOULD BE FORWARDED TO THE NEAREST UK MET. OFFICE FOR ONWARD TRANSMISSION TO MET.O.9

LOW LEVEL WIND SHEAR INVESTIGATION

When operating services into or out of Honington or Brize Norton, pilots are requested to co-operate with the procedure outlined below:-

Warning in Force On all occasions when a warning is in force, the standard reporting form should be completed. If no difficulty is encountered this should be stated. When difficulty is encountered please give as much detail as possible about the wind profile, nature and height of the difficulty experienced etc.

No Warning in Force. Pilots should complete a form only if difficulty is experienced in take-off or landing which might be attributed to wind shear. Give as much information on the difficulty encountered as possible.

ADDITIONAL INFORMATION

The UK Met Office in conjunction with Br. Airways & RAF are evaluating a wind shear forecasting technique at Heathrow, Glasgow and Birmingham, Brize Norton and Honington.

The purpose of the trial is to assess the feasibility of providing a reliable wind shear forecasting service and to determine the value of such forecasts to pilots.

On all occasions when wind shear has been experienced it should be passed verbally to Air Traffic Control at the time and confirmed in writing by filling in this form, the answer to question 16 on which is intended to prevent reports being counted twice in the analysis.

REPORT FORM

Flight and Technical Information

A/C Type ..... Reg ..... Service No ..... Date .....

Captain ..... Base .....

Delete as necessary

1	Aerodrome	Heathrow/Glasgow/Birmingham
2	Runway	.....
3	Phase of Flight	Taking off/Landing
4	Time (GMT)	.....
5	Wind Shear Forecast	Yes/No
6	Wind Shear Experienced	Yes/No

If answer to 6 is YES complete the following

7	Was it	Slight/Moderate/Severe
8	At What Height?	.....ft
9	How was Wind Shear Recognised?	
	IAS increase/decrease ..... knots	
	Height increase/decrease	
	Other symptoms	
10	Did you experience any handling difficulty?	Yes/No
11	Was Autopilot Engaged?	Yes/No
12	Was Autothrottle Engaged?	Yes/No
13	Did you disengage Autopilot?	Yes/No
14	Did you disengage Autothrottle?	Yes/No
15	Additional Information (e.g. any wind measurements made, turbulence experienced etc.	
	.....	
	.....	
16	Was the report passed verbally to ATC	Yes/No

APPENDIX E

SUCCESS PLAN FOR LOW LEVEL WIND SHEAR WARNING SCHEMES DETAILED IN APPENDICES A AND F

PERIOD BEFORE FIRST AIRCRAFT REPORT THAT WARNINGS WERE ISSUED (HOURS)

	More than 3	2-3	1-2	0-1	Period enclosing all aircraft reports of positive shear. All warnings within this period were considered to have been successful.	0-1	1-2	More than 2
Success Code (written a/c reports)	4	3	2	1		2	3	4
(unwritten a/c reports)	4	4	3	2		3	4	4

SUCCESS CODE

1 = Successful

2 = Probably Successful

3 = Probably Unsuccessful

4 = Unsuccessful

Notes

1. This Success Plan is subjective. It has been devised so as to minimise success claims in cases of doubt.
2. Clearcut successs can be regarded as having been achieved only if a warning were issued under any rule before the receipt of an aircraft report. Issue under any rule simultaneously with an issue under Rule 8 confirms the existence of wind shear conditions but is somewhat belated as a forecasting tool.
3. Wind shear conditions may have existed even though no aircraft report was made.
4. (a) The written aircraft reports gave such details as height, intensity of shear, magnitude of indicated airspeed change and other comments.
   (b) The unwritten aircraft reports do not include such additional information as in (a) above.

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APPENDIX F

RULES FOR ISSUING WARNINGS OF LOW LEVEL WIND SHEAR (SUMMER TRIAL JULY TO SEPTEMBER 1977)

NOTATION

$\underline{V}_{10}$ = Surface (10 metre) wind (vector)

V_{10} = $|\underline{V}_{10}|$ = Surface wind speed (scalar)

$\underline{V}_G$ = Gradient (600m, 2,000 ft) wind (vector)

V_G = $|\underline{V}_G|$ = Gradient wind speed (scalar)

RULES

A warning of low level wind shear was issued if

(1) $V_{10} \geqslant$ 30 kn

(2) Not allocated

(3) $|\underline{V}_G - \underline{V}_{10}| \geqslant$ 40 kn

(4) $|\underline{V}_G - \underline{V}_{10}| \geqslant$ 30 kn and an inversion or isothermal layer was present below 600m (2,000 ft)

(5) there were

(a) thunderstorms within 10 km
(b) cumulonimbus clouds within 5 km

} having a component of motion towards the station

of the approach/climbout

(6) from a feature within 50 nm of the station, there was on the approach/climbout a frontal surface or other discontinuity

(a) with a vector wind change across it of at least 10 kn magnitude - noted either locally or from its passage through a nearby station

(b) having a temperature difference across it of at least 5°C

(c) moving at a speed of at least 30 kt

(7) a significant low level jet was suspected at or below 600m.

(8) a report of low level shear had been received from an aircraft.

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LOW LEVEL WIND SHEAR WARNING TRIAL - JULY TO SEPTEMBER 1977

VARIABLES LOGGED HOURLY ON 'OBSERVATION AND WARNING FORM'
(adapted, as shown in Appendix H, from a FORTRAN Coding Form)

Column Numbers	Code Letters	Description
1 - 3	iii	Station Number
5 - 10	MMDDGG	Month ; Day ; Time (GMT) ;
12 - 15	ddff	Most recent H + 50 surface wind (10 minute mean, tens of degrees, whole knots)
17 - 18	$f_g f_g$	Speed of maximum gust in the last hour (whole knots)
20 - 22	$\pm T_a T_a$	Surface dry bulb temperature (whole degs C)
24 - 27	$d_G d_G f_G f_G$	Gradient wind (tens of degrees, whole knots, as measured on the latest available chart)
29 - 32	$d_b d_b f_b f_b$	$(\underline{V_G} - \underline{V_{10}})$ Tens of degrees, whole knots
34	I	Inversion/isothermal layer considered to be present below 600m. (No = Ø; Yes = 1)
35 - 36	$T_i T_i$	Magnitude of temperature inversion within the lowest 600m. Degs C. Estimated from upper air ascents)
38	T	Thunderstorm within 5 km (No = Ø ; Yes = 1)
40	C	Cumulonimbus within 10 km (No = Ø; Yes = 1)
42	M	Does any Cb reported in Col 40 have a component of motion towards the station (No = Ø; Yes = 1)
44	S	Type of front or other discontinuity. (See Code for S below)
45	S_a	Intensity of activity of 'S'. (Weak = 1 ; Moderate = 2 ; Strong = 3)
47 - 48	$f_c f_c$	Observed magnitude of 10 metre wind speed change across S (whole knots)
50 - 51	$f_s f_s$	Speed of S (whole knots)
53 - 55	$\pm T_c T_c$	Surface temperature change across S (whole degs C)
57	J	Low Level Jet. (No = Ø; Yes = 1)
59	W_1	Wind Shear Warning issued or not. See code for W below.
60	W_2	Wind Shear Warning that should, in retrospect, have been issued if, for any reason, different from W_1.

Code for 'S'

Type of Front or other Discontinuity

Ø	No front or other discontinuity
1	Warm front
2	Cold front
3	Occlusion
4	Quasistationary
5	Sea breeze front
6	Non-frontal trough
7	Line squall

Code for W_1 and W_2

Wind Shear Warning Issued or Not

Ø	No warning issued
1	Warning issued for meteorological reasons only (Rules 1 - 7)
2	Warning issued only because of receipt of an aircraft report (Rule 8)
3	Warning issued for both meteorological reasons and receipt of an aircraft report (i.e. Rule 8 and any other Rule)

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LOW LEVEL WIND SHEAR WARNING TRIAL (2)

Summer 1977

FORTRAN Coding Form

i i i . M M D D G G . d d f f . $f_g f_g$. ± $T_a T_a$. $d_G d_G f_G f_G$. $d_b d_b f_b f_b$. I $T_i T_i$. T . C . M . S S_a . $f_c f_c$. $f_s f_s$. ± $T_c T_c$. J . $W_1 W_2$.
Ø Ø
Ø 1
Ø 2
Ø 3
Ø 4
Ø 5
Ø 6
Ø 7
Ø 8
Ø 9	Ø
1 Ø	Ø
1 1	Ø
1 2	Ø
1 3	Ø
1 4	Ø
1 5	Ø
1 6	Ø
1 7	Ø
1 8	Ø
1 9	Ø
2 Ø	Ø
2 1
2 2
2 3

Notes

1. This form is to be filled in for all hours when ATC is open & there is a forecaster on duty.
2. WRITE CLEARLY ; code zeros as Ø and write numeral 'one' as 1
3. Use one line per observation, a maximum of 24 obs per page and one page per day.
4. Enter 99 in cols ~~12~~ 17 and 18 when $f_g f_g$ is less than 10 kt and otherwise enter 9 in all cols for which no other entry is appropriate.
5. Cols ~~33-36~~ 29 32 are (for this second trial) among those to be filled in for all hours.
6. Where consecutive entries are identical either fill them all in or fill in the first and last or a particular entry and join them by a line.
7. Please forward these completed forms to Met.0.9 on the first working day of each week.

Completed forms should be forwarded to:- Superintendent Meteorological Services, Bealine House

Low level wind shear investigation

When operating services into or out of London Heathrow, Glasgow or Birmingham, pilots are requested to co-operate with the procedure outlined below:-

Warning in force
On all occasions when a warning is in force, the standard reporting form should be completed. If no difficulty is encountered this should be stated. When difficulty is encountered please give as much detail as possible about the wind profile, nature and height of the difficulty experienced etc.

No warning in force
Pilots should complete a form only if difficulty is experienced in take-off or landing which might be attributed to wind shear. Give as much information on the difficulty encountered as possible.

Additional information

The UK Met Office in conjunction with British Airways are evaluating a wind shear forecasting technique at Heathrow, Glasgow and Birmingham.

The purpose of the trial is to assess the feasibility of providing a reliable wind shear forecasting service and to determine the value of such forecasts to pilots.

Flight and technical information

Report form

A/C type _____ Reg _____ Service Nr _____ Date _____

Captain _____ Base _____

1	Aerodrome	Delete as necessary Heathrow/Glasgow/Birmingham
2	Runway	_____
3	Phase of flight	Taking off/landing
4	Time (GMT)	_____
5	Wind shear forecast	Yes/No
6	Wind shear experienced	Yes/No
	If answer to 6 is yes complete the following	
7	Was it	Slight/moderate/severe
8	At what height?	_____ ft
9	How was wind shear recognised?	IAS increase/decrease _____ knots Height increase/decrease Other symptoms

10	Did you experience any handling difficulty?	Yes/No
11	Was Autopilot engaged?	Yes/No
12	Was Autothrottle engaged?	Yes/No
13	Did you disengage Autopilot?	Yes/No
14	Did you disengage Autothrottle?	Yes/No
15	Additional information (e.g. any wind measurements made, turbulance experienced etc.)	

	1 LONDON	2 GLASGOW	3 B'HAM	4 CIVIL TOTAL	5 BRIZE NORTON	6 HONING 'TON	7 MARHAM	8 SCAMPTON	9 WADDING 'TON	10 WYTON	11 RAF TOTAL	12 CIVIL & RAF TOTAL
1) Date Trial commenced (Jan 77)	9*	9	9	-	9	10	10	10	10	11	-	-
2) No. of days involved.	97	97	97	-	97	96	69	63	70	67	-	-
3) No. of hours involved.	2328	2328	2328	6984	2328	2304	911	901	1185	821	8450	15434
4) No. of reasons why warnings could have been issued under RULE. 1	1	0	0	1	0	1	0	0	5	0	6	7
2	13	38	13	64	1	4	0	2	0	4	11	75
3	2	35	0	37	0	0	0	0	0	0	0	37
4	9	56	4	69	7	3	2	2	0	0	14	83
5a	10	1	6	17	2	9	2	1	1	0	15	32
5b	75	60	70	205	45	91	33	25	35	27	256	461
6a	39	72	48	159	19	24	2	3	2	17	67	226
6b	2	0	0	2	0	2	0	0	3	0	5	7
6c	28	32	37	97	12	25	4	6	2	7	56	153
7	0	16	0	16	0	4	0	0	12	0	16	32
Totals Rules 1-7	179	310	178	667	86	163	43	39	60	55	446	1113
5) No. of warnings issued under Rules 1-7.	128	243	155	526	73	135	37	36	52	52	385	911
6) No. of warnings issued under Rule 8.	62	51	17	130	5	7	6	5	10	4	37	167
7) Total No. of reasons for which warnings could have been issued under Rules 1-8.	241	361	195	797	91	170	49	44	70	59	483	1280
8) No. of warnings that should have been issued under Rules 1-8	190	294	172	656	78	142	41	41	62	51	415	1071
9) No. of Warnings that were issued correctly.	188	252	166	606	74	132	36	30	74	56	402	1008
10) % of time warnings should have been in force.	8.2	12.6	7.4	9.4	3.3	6.1	4.5	4.4	6.1	6.2	5.0	7.0
11) No. of aircraft reports received.	3 25	54	50	429	22	15	34	3	8	41	123	552
12) No. of positive shear reports rec: a)slight	70	12	10	92	1	0	6	2	2	4	15	107
b)Mod	84	17	20	121	6	4	7	1	5	7	30	151
c)Severe	8	3	3	14	0	0	1	0	0	0	1	15
13) Total No. of positive shear reports.	162	32	33	227	7	4	14	3	7	11	46	273
14) No. of negative shear reports received (on days when forecasts were issued)	163	22	17	202	15	11	20	0	1	30	77	279

*But broadcast on ATIS did not commence until 24 January

SELECTED STATISTICS RELATING TO THE LOW LEVEL WIND SHEAR WARNING TRIAL 1st JULY - 30th SEPTEMBER 1977

	1 LONDON	2 GLASGOW	3 B'HAM	4 CIVIL TOTAL	5 BRIZE NORTON	6 HONING 'TON	7 KINLOSS	8 MARHAM	9 ST. MAWGAN	10 SCAMPTON	11 WADDING 'TON	12 WYTON	13 RAF TOTAL	14 CIVIL & RAF TOTAL
1) Date Trial Commenced (Jul 77)	1.7.77.	1.7.77	1.7.77		1.7.77	1.7.77	1.8.77	1.7.77	1.8.77	1.7.77	1.7.77	1.7.77		
2) No. of Days Involved	92	92	92		92	92	56	70	61	66	69	65		
3) No. of Hours Involved	2208	2208	2208	6624	2208	2208	912	981	1464	855	926	829	10383	17007
4) No. of reasons why warnings could have been issued under RULE. 1	0	0	0	0	0	0	8	0	0	0	0	0	8	8
2														
3	12	16	2	30	0	2	6	0	1	4	0	1	14	44
4	0	6	2	8	0	2	4	0	0	2	0	0	8	16
5a	11	2	2	15	3	2	0	2	4	3	7	0	21	36
5b	13	9	10	32	12	17	1	5	4	3	8	4	54	86
6a	17	35	37	89	15	8	5	7	8	2	0	6	51	140
6b	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6c	3	7	26	36	6	0	0	5	0	1	1	5	18	54
7	5	21	9	35	3	2	0	0	0	8	0	0	13	48
Total Rules 1-7	61	96	88	245	39	33	24	19	17	23	16	16	187	432
5) No. of warnings issued under Rules 1-7.	48	85	68	201	33	29	21	14	13	18	9	13	150	351
6) No. of warnings issued under Rule 8.	17	13	3	33	3	1	1	0	0 0	2	5	0	12	45
7) Total No. of reasons warnings could have been issued under Rules 1-8.	78	109	91	278	42	34	25	19	17	25	21	16	199	477
8) No. of Warnings that should have been issued under Rules 1-8.	60	95	71	226	36	30	22	14	13	19	14	13	161	387
9) No. of Warnings that were issued correctly.	50	73	64	187	30	28	14	13	11	12	14	10	132	319
10) No. of time warnings should have been in force.	2.7	4.3	3.2	3.4	1.6	1.4	2.4	1.4	0,9	2.2	2.7	1.6	1.6	2.3
11) No. of aircraft reports received.	52	10	2	64	5	9	16	26	0	22	9	10	97	161
12) No. of positive shear reports rec:														
a)Slight	5	3	0	8	1	3	12	6	0	6	2	0	30	38
b)Mod	16	2	0	18	3	0	2	10	0	7	4	2	28	46
c)Severe	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13) Total of positive shear Reports.	21	5	0	26	4	3	14	16	0	13	6	2	58	84
14) No. of negative shear Reports received (on days when forecasts were issued).	31	5	2	38	1	6	2	10	0	9	3	8	39	77

CONCLUSION Of the 432 meteorological reasons (ie. excluding aircraft reports) why 351 wind shear warnings were issued, preliminary indications are that 26 were correct, 15 were probably successful, 12 were probably unsuccessful, and 299 were unsuccessful.

APPENDIX L OVERALL SUMMARY OF SUCCESS (Rules 1-7 only) WINTER TRIAL (January - April 1977)

A. BY STATION	1 LONDON	2 GLASGOW	3 B'HAM	4 CIVIL TOTAL	5 B'NORTON	6 HON'TON	7 MARHAM	8 SCAMPTON	9 WADDING 'TON	10 WYTON	11 RAF TOTAL	12 CIVIL &RAF TOTAL		
a. Total Nos. of reasons why warnings could have been issued for Rules 1-7	179	310	178	667	86	163	43	39	60	55	446	1113		
b. Nos. of warnings that should have been issued under Rules 1-7	128	243	155	526	73	135	37	36	52	52	385	911		
c. Nos. of (b) considered to have been successful	46	29	16	91	3	3	2	0	5	7	20	111		
d. Nos. of (b) considered to have been probably successful	12	13	11	36	5	2	3	0	3	5	18	54		
e. Nos. of (b) considered to have been probably unsuccessful	10	14	11	35	3	0	1	0	2	1	6	41		
f. Nos. of (b) considered to have been unsuccessful	40	35	22	97	20	12	10	0	6	16	14	161		
g. Totals (c)to (f)	108	91	60	259	31	17	16	0	16	29	104	367		
h. No. of unsubstanciated successes because no written or unwritten a/c reports were received. (b)-(g)	20	152	95	267	42	118	21	36	36	23	277	544		

B. BY RULE	1	2	3	4a	4b	5a	5b	6a	6b	6c	7	Total		
a. Total No. of reasons why warnings could have been issued under rules 1-7	7	75	37	83	-	32	461	226	7	153	32	1113		
b. Total No. of warnings that should have been issued under rules 1-7												911		
c. No. of b) considered to have been successful	1	$6\frac{5}{6}$	$2\frac{1}{3}$	4	-	3	51	$20\frac{1}{6}$	$\frac{1}{3}$	$19\frac{1}{3}$	3	111		
d. No. of b) considered to have been probably successful	0	$2\frac{1}{2}$	3	2	-	$\frac{1}{2}$	$30\frac{5}{6}$	$8\frac{1}{3}$	0	$5\frac{5}{6}$	1	54		
e. No. of b) considered to have been probably unsuccessful	0	$4\frac{1}{2}$	4	3	-	$\frac{1}{2}$	$19\frac{5}{6}$	$4\frac{1}{3}$	$\frac{1}{2}$	$4\frac{1}{3}$	0	41		
f. No. of b) considered to have been unsuccessful	2	12	$5\frac{1}{3}$	$30\frac{1}{3}$	-	$3\frac{1}{2}$	$45\frac{1}{2}$	34	0	$24\frac{1}{3}$	4	161		
g. Total c to f i.e. Total No. with any success category	3	$25\frac{5}{6}$	$14\frac{2}{3}$	$39\frac{1}{3}$	-	$7\frac{1}{2}$	$147\frac{1}{6}$	$66\frac{5}{6}$	$\frac{5}{6}$	$53\frac{5}{6}$	8	367		
RATIO $\frac{c}{g}$	0.33	0.26	.15	0.10		0.4	.34	.30	.39	.35	.37	.30		

from 113

CONCLUSION Out of 911 warnings that should have been issued ∧ purely meteorological reasons, we are able to say something about the success or otherwise of 367 of them but cannot say anything about the remaining 544. Of the 911, 111 were successful, 54 were probably successful, 41 were probably unsuccessful, 161 were unsuccessful and for the remaining 544 we 'don't know'.

APPENDIX M OVERALL SUMMARY OF SUCCESS (Rules 1-7 only) SUMMER TRIAL July - Sept 1977

A. BY STATION	1 LONDON	2 GLASGOW	3 B'HAM	4 CIVIL TOTAL	5 B'NORTON	6 HON'TON	7 KINLOSS	8 MARHAM	9 St. MAW-GAN	10 SCAMPTON	11 WADDING-TON	12 WYTON	13 RAF TOTAL	14 CIVIL & RAF TOTAL
a. Total Nos. of reasons why warnings that could have been issued for Rules 1-7	61	96	88	245	39	33	24	19	17	23	16	16	187	432
b. Nos. of warnings that should have been issued under Rules 1-7	48	85	68	201	33	29	21	14	13	18	9	13	150	351
c. Nos. of (b) considered to have been successful	9	7	0	16	1	2	0	4	0	1	2	0	10	26
d. Nos. of (b) considered to have been probably successful	4	5	0	9	1	2	0	0	0	2	1	0	6	15
e. Nos. of (b) considered to have been probably unsuccessful	5	2	0	7	1	1	1	0	0	1	1	0	5	12
f. Nos. of (b) considered to have been unsuccessful	9	3	7	19	0	0	4	4	0	1	2	0	11	30
g. Totals (c) to (f)	27	17	7	51	3	5	5	8	0	5	6	0	32	83
h. No of unsubstantiated successes because no written or unwritten a/c reports were (b) - (g) received.	21	68	61	150	30	24	16	6	13	13	3	13	118	268

B. BY RULE				1	2	3	4	5a	5b	6a	6b	6c	7	Total
a. Total No. of reasons why warnings could have been issued under rules 1-7				8		44	16	36	86	140	0	54	48	432
b. Total No. of warnings that should have been issued under rules 1-7														351
c. No. of b) considered to have been successful				0		$11\frac{1}{2}$	$1\frac{1}{2}$	$2\frac{1}{2}$	3	$3\frac{1}{2}$		3	1	26
d. No. of b) considered to have been probably successful				0		$3\frac{1}{3}$	$\frac{5}{6}$	$1\frac{1}{2}$	$3\frac{1}{3}$	5		1	0	15
e. No. of b) considered to have been probably unsuccessful				0		4	0	1	2	4		0	1	12
f. No. of b) considered to have been unsuccessful				3		4	1	$1\frac{1}{2}$	$5\frac{1}{2}$	6		6	3	30
g. Total c to f i.e. Total No. with any success category				3		$22\frac{5}{6}$	$3\frac{1}{3}$	$6\frac{1}{2}$	$13\frac{5}{6}$	$18\frac{1}{2}$	0	10	5	83
RATIO $\frac{c}{g}$				0	-	0.50	0.45	0.38	0.22	0.19	0	0.30	0.20	0.31

APPENDIX N ANALYSIS IN RELATION TO HEIGHT OF WIND SHEAR EITHER REPORTED AS SEVERE OR ASSOCIATED WITH AIRSPEED CHANGES OF 20KN OR MORE.

AIRSPEED CHANGE (NUMBER OF CASES WINTER TRIAL; JANUARY TO APRIL 1977) See Note (iii)

AIRSPEED RANGE (KN)	WIND SHEAR INTENSITY	INCREASE H1	INCREASE H2	INCREASE H3	INCREASE H4	DECREASE H1	DECREASE H2	DECREASE H3	DECREASE H4	INCREASE AND DECREASE H1	INCREASE AND DECREASE H2	INCREASE AND DECREASE H3	INCREASE AND DECREASE H4	INCREASE OR DECREASE NOT GIVEN H1	INCREASE OR DECREASE NOT GIVEN H2	INCREASE OR DECREASE NOT GIVEN H3	INCREASE OR DECREASE NOT GIVEN H4	TOTALS H1	TOTALS H2	TOTALS H3	TOTALS H4	GRAND TOTALS
≤10	Slight																					
	Moderate																					1
	Severe										1								1			
10-19	Slight																					
	Moderate																					5
	Severe	1	2			1	1											2	3			
≥20	Slight				/		1		1 at 1300 Ft.										1			
	Moderate	1	5	2	/	2*	1		/			1	1 Mdte to Severe 1500-100 Ft.				2 at < 2000ft.	3*	6	3	5*	25
	Severe	1	1	1	/	1	2	1	/									2	3	2		
	Unspecified				1 AT 1500 Ft.																	
AIRSPEED CHANGE Not Given																						
	Slight																					
	Moderate				1 Ht. Not Given																2	2
	Severe																1 1500 - 3000 Ft					
ALL CASES	Slight						1		1									0	1	0		
	Moderate	1	5	2	2*	2	1					1	1*				2	3*	6	3	7*	
	Severe	2	3	1		2	3	1			1						1	4	7	2		
	TOTALS	3	8	3	2	4	5	1	1		1	1	1				3	7	14	5	7	33 (See Note ii)

* include one of 15-20 Kn

0 < H1 ≤ 200ft.
200 < H2 ≤ 600
600 < H3 ≤ 1000
1000 < H4 ≤ other height specifications

Notes

(i) The total number of cases for speeds ≥ 20 kt. was 25 of which 20 occurred at heights of 1,000 ft. or below.

(ii) Of the total of 33, 26 were at 1,000 or below.

(iii) There were 4 cases of an airspeed change ≥ 20 kn. in the Summer Trial. They are not included in the above Table. Para 4.3.2. refers.